NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

COMPUTING REQUISITIONING OBJECTIVES
FOR THE KOREAN AIR FORCE INVENTORY
MANAGEMENT SYSTEM

by

Choi, Sung Kyu

December 1989

Thesis Advisor: Dan Trietsch

Approved for public release; distribution is unlimited.

Unclassified

security classification of this page

REPORT DOCUMENTATION PAGE

1a Report Security Classification Unclassified		1b Restrictive Markings			
2a Security Classification Authority		3 Distribution Availability of Report Approved for public release; distribution is unlimited.			
2b Declassification Downgrading Schedule					
4 Performing Organization Report Number(s)		5 Monitoring Organization Report Number(s)			
6a Name of Performing Organization Naval Postgraduate School	6b Office Symbol *(if applicable)* 36	7a Name of Monitoring Organization Naval Postgraduate School			
6c Address *(city, state, and ZIP code)* Monterey, CA 93943-5000		7b Address *(city, state, and ZIP code)* Monterey, CA 93943-5000			
8a Name of Funding Sponsoring Organization	8b Office Symbol *(if applicable)*	9 Procurement Instrument Identification Number			
8c Address *(city, state, and ZIP code)*		10 Source of Funding Numbers			
		Program Element No	Project No	Task No	Work Unit Accession No

11 Title *(include security classification)* COMPUTING REQUISITIONING OBJECTIVES FOR THE KOREAN AIR FORCE INVENTORY MANAGEMENT SYSTEM

12 Personal Author(s) Choi, Sung Kyu

13a Type of Report Master's Thesis	13b Time Covered From To	14 Date of Report *(year, month, day)* December 1989	15 Page Count 104

16 Supplementary Notation The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.

17 Cosati Codes			18 Subject Terms *(continue on reverse if necessary and identify by block number)*
Field	Group	Subgroup	Requisition Objectives,Inventory,EOQ, METRIC

19 Abstract *(continue on reverse if necessary and identify by block number)*

This thesis investigates the structural inconsistency of the Korean Air Force's inventory management system for aircraft spare parts. Recommendation for solving key problems in the inventory system including the Requisitioning Objectives computational methods are provided.

Additionally, this study provides Korean Air Force personnel with a greater understanding of their inventory models and Requisioning Objectives (RO) concepts. Several inventory system models in the literature, including those used in the U.S. Air Force and the U.S. Navy, are explained.

20 Distribution Availability of Abstract ☒ unclassified unlimited ☐ same as report ☐ DTIC users	21 Abstract Security Classification Unclassified	
22a Name of Responsible Individual Dan Trietsch	22b Telephone *(include Area code)* (408) 646-2456	22c Office Symbol 54Tr

DD FORM 1473,84 MAR — 83 APR edition may be used until exhausted. All other editions are obsolete — security classification of this page

Unclassified

Approved for public release; distribution is unlimited.

Computing Requisitioning Objectives for the Korean Air Force Inventory Management System

by

Choi, Sung Kyu
Captain, Republic of Korea Air Force
B.A., Korea Air Force Academy, 1982

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN MANAGEMENT

from the

NAVAL POSTGRADUATE SCHOOL
December 1989

ABSTRACT

This thesis investigates the structual inconsistency of the Korean Air Force's inventory management system for aircraft spare parts. Recommendation for solving key problems in the inventory system including the Requisitioning Objectives computational methods are provided.

Additionally, this study provides Korean Air Force personnel with a greater understanding of their inventory models and Requisioning Objectives (RO) concepts. Several inventory system models in the literature, including those used in the U.S. Air Force and the U.S. Navy, are explained.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

TABLE OF ABBREVIATIONS

AFLC	U.S. Air Force Logistics Center
AL	Additional Level
ALC	U.S. Air Logistics Center
ASO	Aviation Supply Office
AVCAL	Aviation Coordinated Allowance Lists
CIRF	Centralized Intermediate Repair Facility
CLSSA	Coorperative Logistic Supply Support Arrangement
COSAL	Coordinated Shipboard Allowance List
DAM	Depot of Ammunition Maintenance
DAP	Directorate of Procurement
DDR	Daily Demmand Rate
DECM	Depot of Electronic and Communication Maintenance
DME	Depot of Maintenance and Engineering
DMM	Directorate of Maintenance Management
DRP	Depot Repair Percentage
DSM	Directorate of Supply Management
DST	Depot of Storage and Transportation
EDPC	Electrical Data Processing Center
EOQ	Economic Order Quantity
FL	Fixed Level
FLSIP	Fleet Logistics Support Improvement Program
FMC	Full Mission Capability
FMS	Foreign Military Sales
IM	Item Manager
LRU	Line Replacement Unit
LTD	Lead Time Demand
MAD	Mean Absolute Deviation
METRIC	Multi-Echelon Technique for Recoverable Item Control
ML	Minimum Level

MOD-METRIC	Modified METRIC
MRRL	Material Repair Return List
MRS	Material Repair Schedule
NMC	Non-Mission Capable
OLQ	Operation Level Quantity
OSTQ	Order and Shipping Time Quantity
RCQ	Repair Cycle Quantity
RCT	Repair Cycle Time
RO	Requisitioning Objectives
ROKAF	Republic of Korea Air Force
SBSS	Standard Base Supply System
SIM	Selective Inventory Management
SLQ	Safety Level Quantity
SMGC	Supply Management Group Code
SOS	Source of Supply
SPCC	Ships Part Control Center
SRU	Shop Replacement Unit
UP	Unit Price
WRM	War Reserved Material
XL	Maximum Level

I. INTRODUCTION

A. BACKGROUND

With the Military Aid Program (MAP) from the U.S.A, the Korean Air Force had no need for any kind of aircraft spare parts management until the late 1960's. The inventory management initiatives by the Korean Air Force started in the early 1970's with the introduction of a model used by the U.S. Air Force in the early days of economic inventory models. The model adopted in the 1970's has never been reviewed or analyzed systematically since its adoption by the Korean Air Force . The performance of the model has declined as the weapon systems used in the Korean Air Force have become more complex and expensive than ever, and the overall size of the Korean Air Force has increased.

In fact, recently, the Korean Air Force has introduced many new aircraft types. It has depended on the U.S.A to support the replenishment materials for those aircraft through the Foreign Military Sales (FMS). As a result of a new constrained budgeting atmosphere, the Korean Air Force (ROKAF) has tried to manufacture or repair replenishment parts in Korea. Some items purchased via the FMS channel before were switched to conmmercial channels because ROKAF could offer cheaper and faster service. To date, the ratio of procurement by source of supply is about 65 percent through FMS channel, three percent from foreign commercial contractors, and 32 percent of domestics suppliers.

With the increased complexity of the inventory system and increased budget constraints, the Korean Air Force Logistics Command is attempting to resolve the dilemma of surplus and stock-out of aircraft spare parts. To resolve this dilemma, the Korean Air Force supply personnel determined that one of major reasons is caused by using the inappropriate Requisitioning Objectives (RO) computation method, and another reason is that they didn't consider the budget constraint and the source of supply.

B. OBJECTIVES

This thesis investigates the structual inconsistency of the Korean Air Force inventory management system and identifies the key problems related to effective inventory management. Then, this thesis recommends a particular inventory management method.

The research also provides Korean Air Force personnel a greater understanding of their inventory models and Requisitioning Objectives (RO) concepts, several inventory system models in the literature, the U.S. military inventory system used in U.S. Air Force and U.S. Navy, and a recommendation for solving key problems in their inventory system and their RO computation method.

C. SCOPE OF THE THESIS

This thesis suggests an alternative method to establish maximum operational benefits under a given budget that avoids freezing excessive capital and stockouts.

This thesis reviews the inventory system models in the literature and in the U.S. military. The review includes the evaluation of the current Korean Air Force Inventory System through comparison to the other systems and their Measures of Effectiveness (MOE) and through a case analysis.

This thesis will be limited to the discussion of the peace time supporting for the spare parts of aircraft.

D. ORGANIZATION OF THE THESIS

The first chapter of this thesis introduces the need for developing an alternative method to current Requisitioning Objectives (RO) computation method in the Korean Air Force inventory system. Chapter II reviews the current Korean Air Force inventory management system. This review includes the description of the organizations involved, the general scheme of the system, and mathematical approach to the problems.

In Chapter III, the applicable inventory literature and U.S. military inventory models are introduced to show a mathematical approach to solving the inventory problems.

Chapter IV describes the results of analysis and comparison among the inventory models. The results include case studies for each inventory model.

Finally, Chapter V is a summary of this study.

II. OVERVIEW OF KOREAN AIR FORCE INVENTORY MANAGEMENT

A. INTRODUCTION OF SUPPLY SUPPORT SYSTEM

This section presents the Korean Air Force supply support system, its organizational and functional responsibilities, and the source of supply (SOS) of materials that are required.

1. Organization and Function

The major supply organizations are divided among the logistics staff of Headquarters of the Korean Air Force, the Korean Air Force Logistics Command (AFLC), and the supply squadrons of each air base.

Logistics staff of Headquarters of the Korean Air Force has two divisions - Division of Equipment Management and Division of Requirement and Procurement - for overall control of the supply support system. Division of Equipment Management is responsible for establishing basic supply support policies, managing supply personnel, and making decisions related to the introduction of new general equipment. Division of Requirement and Procurement is responsible for budgeting for logistics parts, executing and auditing of budgets, cataloging, etc.

Figure 1 on page 4 shows the organization of Korean AFLC.

The Korean Air Force Logistics Command has a substantial responsibility for overall supply and maintenance support. It performs the role of an wholesale level inventory management and directs and controls the intermediate and consumer level supply units. It has five general staffs: Directorate of Resource and plans, Directorate of Personnel and Administration, Directorate of Supply Management, Directorate of Maintenance Management, and Electrical Data Processing Center (EDPC) Division. The Korean Air Force Logistics Command also has seven special staffs which support the commander for special parts, and five line units: Depot of Maintenance and Engineering (DME), Depot of Electronics and Communication Maintenance (DECM), Depot of Ammunition Maintenance, Depot of Storage and transportation (DST), and the Directorate of Procurement (DAP).

Since the scope of this study does not deal with the overall Korean Air Force Logistics policies, only the organizations within the Korean Air Force Logistics Command which have an important effect upon inventory management will be introduced.

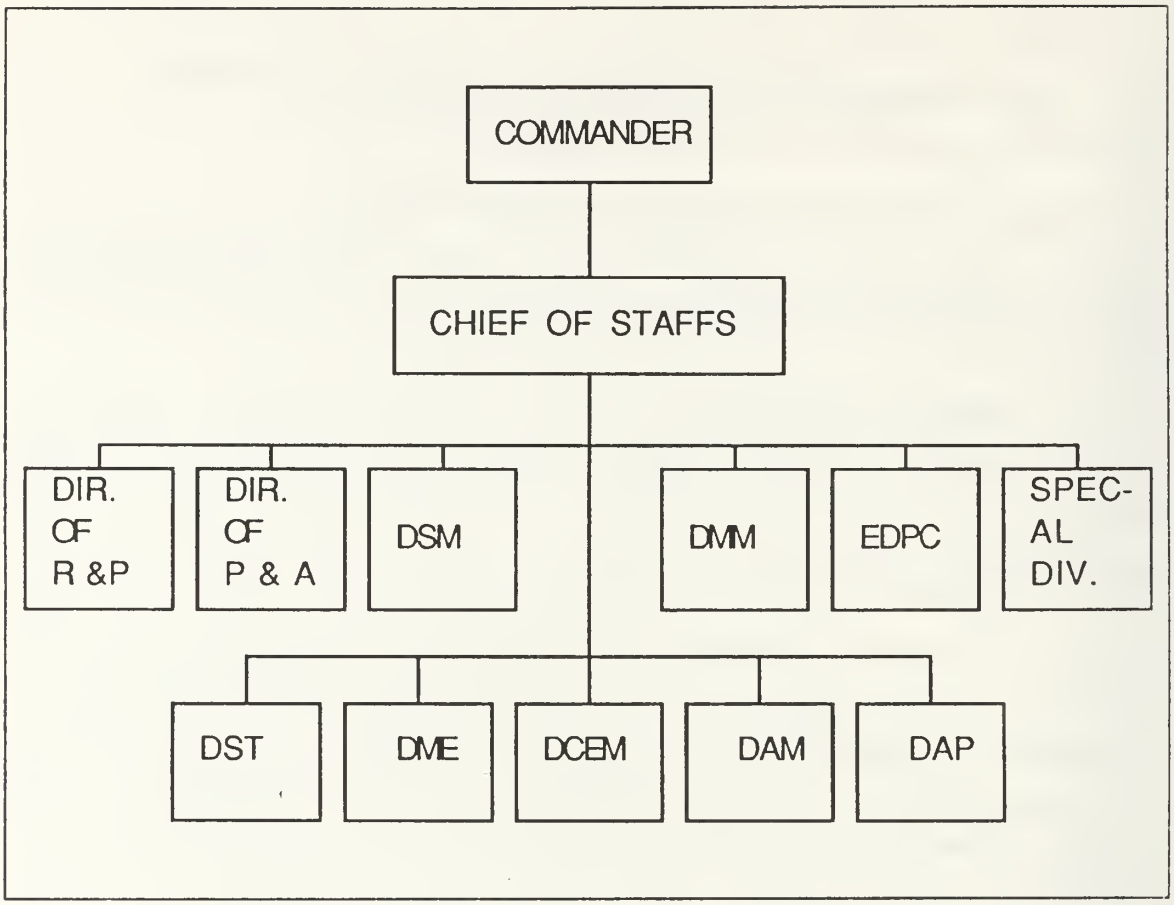

Figure 1. The Organization of Korean AFLC

The DSM is the focal point of material management for the Korean Air Force. Under the policies of the AFLC, it procures all materials according to its estimates of requirements, and distributes the material to all of the tactical units and the supporting units within the Korean Air Force. Thus, the DSM is the equivalent of a wholesale level inventory control point. The DSM manages approximately 250,000 items. These items are managed by about 200 item managers at the DSM. Item Managers place orders for procurement, repair, and issue stocks upon orders from each base. Finally, they update the system program files to reflect these transactions.

The DST is the centralized warehouse for the Korean Air Force where all procured and repaired materials including consumables, are stored. Even though the DSM manages all material transactions and files historical data , the DST is the sole location where the materials are physically stored. The DSM exercises administative control of

material management. The DST provides the transportation method for the moving of depot materials.

The Depots of Maintenance perform the maintenance of repairables which cannot be repaired at the base maintenance squadron. Their major mission is the overhaul of the end item such as aircraft, ground support equipment and radio sets, and the regeneration of the Non-Ready for issue items.

The EDPC provides logistics software development and support, establishes job processing standardization, collects data, and provides analysis and guidance for each of the other major divisions. The EDPC installed a PRIME 9950 computer with 16 terminals in 1985. The DSM uses its terminals only for inquiries concerning material backorders, issues, receipts and inventory balances. The DMM uses its terminals for inquiries concerning depot maintenance scheduling status for repairables.

The base supply squadron acquires materials needed for base maintenance operations form the DSM in Korean Air Force Logistics Command. Using historical demand data, it maintains a level of stocks to satisfy their demands.[Ref. 1: part two]

2. Source of Supply

The Korean Air Force largely divides the source of supply (SOS) into two categories - domestic and overseas. Figure 2 on page 6 shows the procedure to decide the source of supply of each items.

The rate of domestic procurement is about 64 percent of total annual logistics budgets. Item Managers have to budget for items which are required to be replenished once per year. Overseas procurement includes FMS and commercial channels. The FMS secondary item requirements are processed in accordance with procedures which vary according to case type, category of demand, military department, and other factors specific to particular requisitions. There are three types of FMS cases as shown below. [Ref. 2 : pp. 8 - 11] :

- *Defined Order Cases provide the foreign countries with their initial secondary item stocks, with secondary items in support of subsequent end item procurement, and one-time requirements for secondary items.*
- *Coorperative Logistic Supply Support Arrangement (CLSSA) provides continuing follow-on support from U. S. stocks. Under CLSSAs, foreign countries make equity investments to increase U.S. stocks and receive support equivalent to that provided U.S. Air Forces.*
- *Blanket Order Cases provide follow-on support from U.S. stocks but without foreign country equity investment to increase U.S. stocks. Under Blanket Order Case, foreign countries receive support on a not-to-interfere basis.*

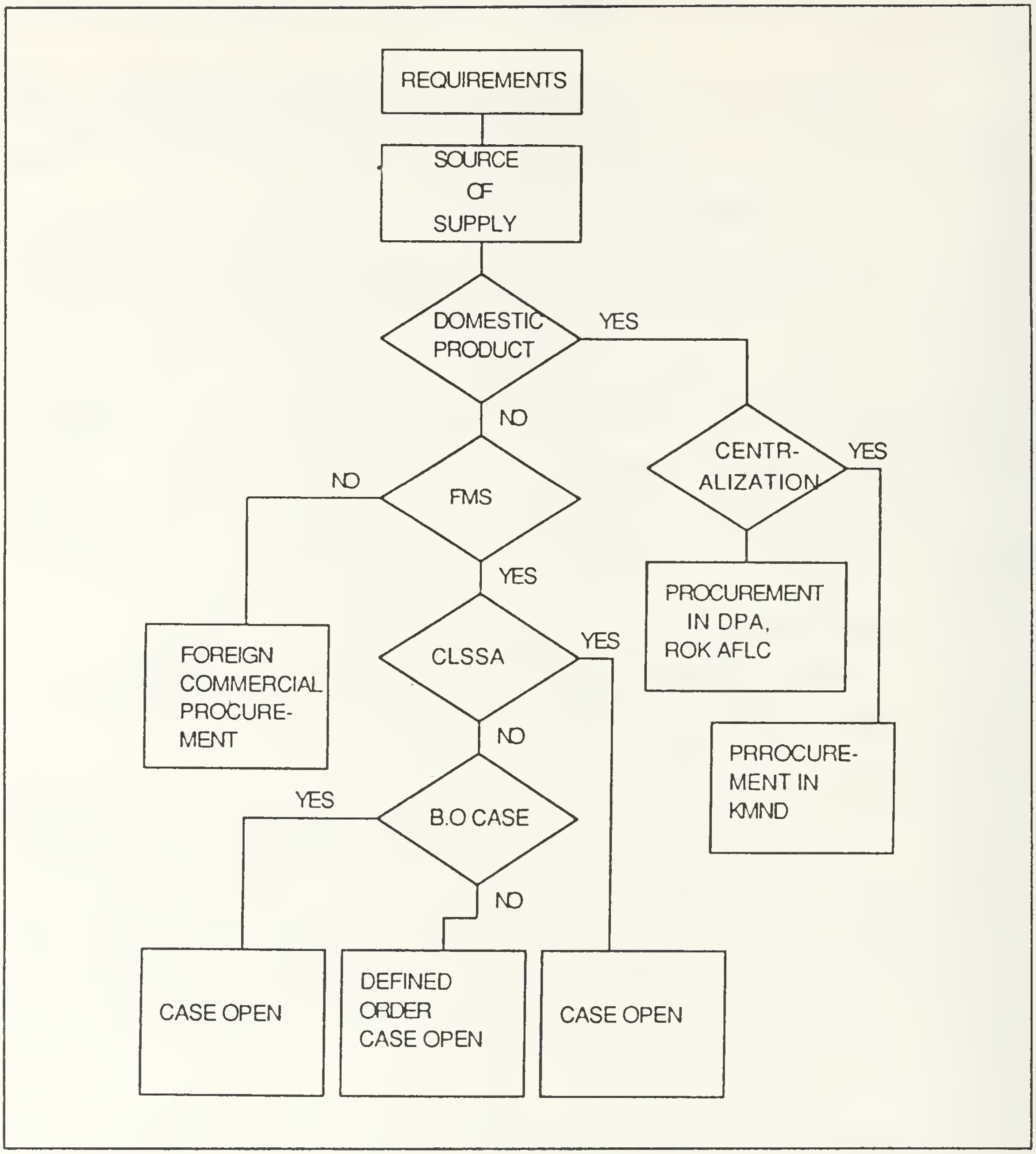

Figure 2. The procedure of choosing the SOS

The items beyond domestic procurement and FMS channels are procured through commercial procurement channels such as General Electrics (GE) Company, or through brokers (offer agents).

Overseas procurement is very critical for supporting secondary items.

B. PROPERTIES OF THE KOREAN AIR FORCE INVENTORY SYSTEM

To manage the inventory of aircraft spare parts effectively, the following characteristics should be fulfilled.

1. Reliability

Reliability is an important factor influencing the frequency. The goal of reliability design and engineering is to achieve a failure rate level for a piece of equipment, end items or weapon systems that represents the maximum cost effectiveness and minimum total cost of ownership. In other words, the reliability goal is the greatest probability of mission success for a given cost or a given probability of success for the least cost. The Korean Air Force target is 95 percent reliability.

2. Responsiveness and Timeliness

The time factor involves the long process of production and distribution required before goods reach the final consumer. Time is required to develop the production schedule, make raw material requisitions, ship raw material from suppliers (transit time), inspect raw materials, produce the product, and ship the product to the wholesaler or consumer (transit time). Most secondary items are required for the support of the Korean Air Force are also procured through the FMS channel. Then, the Korean Air Force tries to minimize the transit time of those items.

3. Flexibility

The improvement of operational availability of aircraft is the most important requirement in the logistics area . The goal of the Korean Air Force is 90 percent operational availability. Avoiding the delay in supply support is critical to reach this goal. Korean Air Force has been looking for substitutes for major critical items to decrease the risk of stock-out.

4. Economy

The economy factor permits the organization to take advantage of cost reducing alternatives. It enables an organization to purchase or produce items in economic quantities. Although bulk purchases with quantity discounts can reduce procurement costs significantly, it may cause a surplus or excess condition in an inventory management system. Standardization is very important for economy.

C. THE INVENTORY MANAGEMENT OBJECT OF AIRCRAFT PARTS

The secondary items are classified to two objects: repairable items and consumable items.

1. Repairable items

A repairable item also referred to as an investment item, is an item of supply that can be made to function by a repair process after it breaks. Repairable items are usually the most expensive parts or components in weapons and aircraft systems. Some examples include gearboxes, circuit boards, gyroscopes, and electronic black boxes.

2. Consumable items

This is material which is consumed in use after issue from stock to the final user, or which becomes incorporated in other property while having continuing life. Generally, consumable items are not repaired when unfit for further service. Consumable items are referred to as expense items . Wholesale level inventory managers treat field level repairables as consumable items because they are repaired below the depot level. Examples include bolts and nuts.

D. THE INVENTORY MANAGEMENT MODEL AND RO COMPUTATION

1. Definition of system parameters and variables

Some parameters and variables are officially defined and applied within the Korean Air Force Logistics Command.

a. Daily Demand Rate (DDR)

The DDR is the average quantity used daily and is computed in the following formula.

$$DDR = \frac{\text{The annual demands}}{365}$$

b. Depot Repair Percentage (DRP)

This is the repair rate of the Korean Air Force's maintenance depot for the current and past three years.

$$DRP = \frac{RTS \times 100}{RTS + NRTS + \text{Condemned}}$$

where

RTS = Repair this station.

NRTS = Non-repair this station.

c. Material Repair Schedule (MRS)

The MRS is the repair schedule of the Non-Ready for Issue (NRFI) items in the Korean Air Force's maintenance depot. The Item Manager (IM) forecasts the demand for each repairable for the next year and total repair quantity. The repair requirements for the next year are provided to the maintenance depot. The maintenance depot then sets up the MRS through the DSM. The repair requirements which are beyond the capability of the maintenance depot are turned over to the FMS channel (MRRL through CLSSA). The repair quantity is readjusted on a quarterly basis.

d. Material Repair Return List (MRRL)

The MRRL is the list of repairables for which the U.S. Air Force approves the Korean Air Force's return carcasses under the current FMS case that is established between U.S. military and ROKAF. In the case of MRRL repair, the DST sends a carcass to the USAF maintenance depots. Upon receipt of carcasses from the Korean Air Force, the USAF sends servicable units back to the Korean Air Force.

e. Operation Level Quantity (OLQ)

This refers to the inventory stockage which is actually stored in maximum quantity level for each item. Korean Air Force personnel apply the following formula for consumable items and MRRL items:

For consumable items

$$OLQ = \frac{4.4 \times \sqrt{DDR \times 90 \times UP}}{UP}$$

where UP = Unit Price For repairable items which cannot be repaired in Korea (MRRL)

$$OLQ = DDR \times 60$$

The operation level is the most economical amount of stock needed to perform the day-to-day mission.

f. Repair Cycle Time (RCT)

The Korean Air Force has two kinds of repair cycle times: the repair cycle time of base maintenance and depot level maintenance. According to the view of the

depot level, items repaired at the base level would be considered as consumables. RCT refers to the time allowance for the depot level maintenance only. In the DSM, RCT is constrained to be between 30 and 120 day.

g. Repair Cycle Quantity (RCQ)

The RCQ is the repairables stocked to meet demands during the repair time. RCQ is applied to the MRS items only and it is computed as follows:

$$RCQ = DDR \times RCT \times DRP$$

where

DDR = Daily Demand Rate

RCT = Repair Cycle Time

DRP = Depot Repair Percentage

h. Order and Shipping Time (OST)

The OST is the average elapsed time, in days , between the initiation and receipt of stock replenishment requisitions. In case of procurement, the Korean Air Force constrains the OST to be not less than 120 days and not greater than 365 days. In case of repair, the OST is constrained to be not less than 220 days and not greater than 465 days. Both the upper and lower bounds are adopted to avoid extremes in the OST. The 100-day increment in the OST is due to the additional transportation time for MRRL items from Korea to Continental U.S.A. For the items without historical data, the upper bound OST is adopted.

i. Order and Shipping Time Quantity (OSTQ)

The OSTQ is the quantity required to be on hand to meet demands during the period represented by the Order and Shipping Time. The following formula is given for the OSTQ:

For consumable items,

$$OSTQ = DDR \times OST$$

For MRS items,

$$OSTQ = DDR \times NDRP \times OST$$

For MRRL items,

$$OSTQ = DDR \times OST$$

j. Safety Level Quantity (SLQ)

The SLQ are those assets required to be on hand to permit continuous operation in the event of minor interruption of normal replenishment or predictable increases in demand. The SLQ is computed as follows:

For consumable items,

$$SLQ = \sqrt{3 \times OSTQ}$$

For MRS items,

$$SLQ = \sqrt{3 \times RCQ + OSTQ}$$

For MRRL items,

$$SLQ = \sqrt{3 \times OLQ + OSTQ}$$

2. Inventory Model and the Determination of R/O

a. Korean Air Force Inventory Model

The DSM applies a periodic review system that is based on a policy of reviewing and ordering at regular fixed intervals. In this control system, the inventory position is checked at the end of every three months. EDPC used to relevel the RO which is based on current quarter demand at the end of three months. If the inventory position is found to be below a relevelling Requisitioning Objectives (RO), then an order is placed which is large enough to bring the inventory position back up to the level of the RO.

In this system, two decision variables are available for T, the review interval, and for RO, the requisitioning objectives. Because orders are placed at predetermined intervals without examining the stock position at times between orders, the value of RO should be set equal to the expected demand between reorders, plus some allowance for the variability of demand.

As shown in the Figure 3 on page 13 , the reorder quantity is the difference between releveling RO and the on-hand inventory at the time of review.

b. The Determination of RO

A Requisitioning Objective (RO) is the maximum quantity that should be on hand and/or on order to sustain current operations. RO is computed for each item during the requirements computation process according to the following formula:

For consumable items,

$$RO = SLQ + OLQ + OSTQ$$

where

$$SLQ = \sqrt{3 \times OSTQ}$$

$$OLQ = \frac{4.4 \times \sqrt{DDR \times 90 \times UP}}{UP}$$

$$OSTQ = DDR \times OST$$

For MRS items,

$$RO = SLQ + RCQ + OSTQ$$

where

$$SLQ = \sqrt{3 \times (RCQ + OSTQ)}$$

$$RCQ = DDR \times RCT \times DRP$$

$$OSTQ = DDR \times NDRP \times OST$$

For MRRL items,

$$RO = SLQ + OLQ + OSTQ$$

where

$$SLQ = \sqrt{3 \times (OLQ + OSTQ)}$$

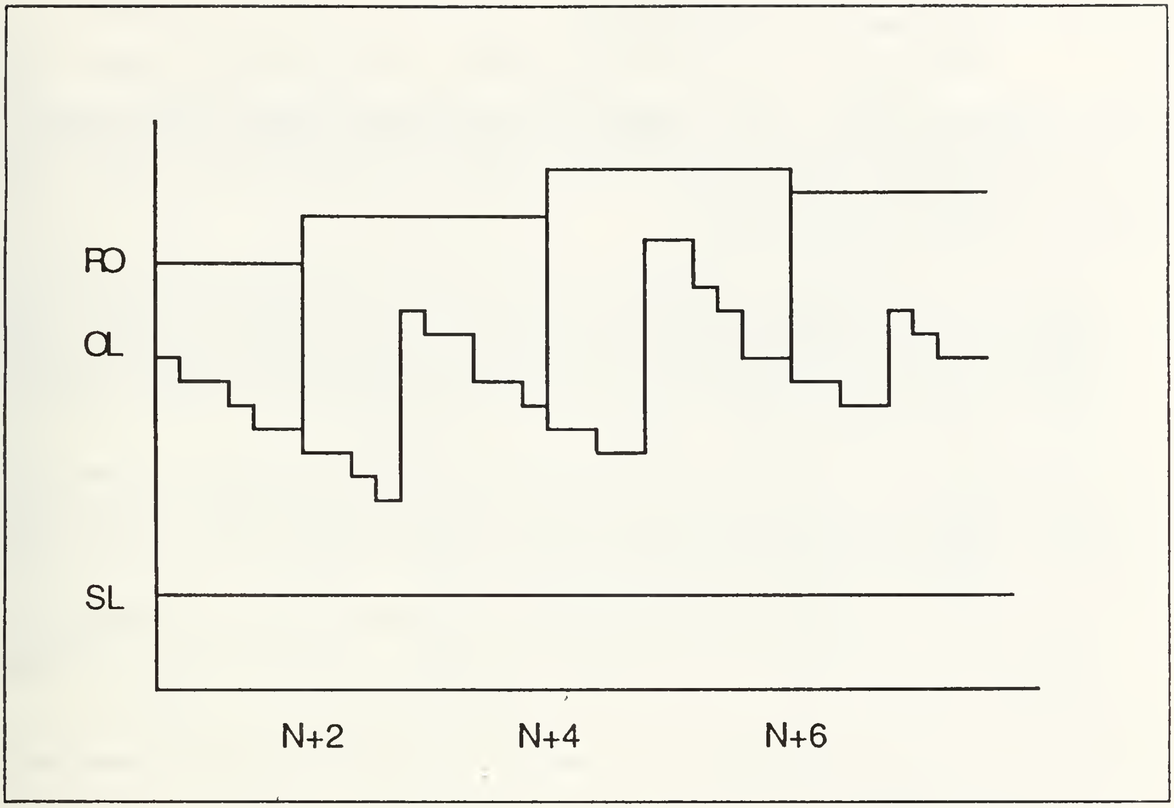

Figure 3. The Korean Air Force Inventory Model

$$OLQ = DDR \times 60$$

$$OSTQ = DDR \times OST$$

Table 1 shows the relationship between the RO and other factors.

Table 1. THE RELATIONSHIP BETWEEN RO AND OTHER FACTORS

<table>
<tr><td rowspan="3">RO = maximum of assets</td><td>EOQ</td><td>OL</td><td rowspan="2">Stockage Objectives (SO) = maximum of on-hand</td></tr>
<tr><td rowspan="2">Reorder Point = minimum of assets</td><td>SL</td></tr>
<tr><td>OST</td><td>other factors</td></tr>
</table>

So, the RO equal the sum of SL, OL, and OST and also is indicated as follows: $RO = SO + OST$ and $RO = RP + EOQ$

c. *The Constraint of Special Level*

When the RO based on the past demand is inappropriate to support the future demand due to the variance of demand or known demand, the IMs can apply to the following special levels: Minimum Level (ML), Maximum Level (XL), Fixed Level(FL), Additional Level (AL).

- *Minimum Level (ML); The ML is considered if the demand is expected to increase because of circumstances such as the introduction of new equipment, a one time maintenance schedule, and modification of major equipment. If a minimum level is loaded, the minimum level is compared to the demand level and the greater is used as the RO. For example, if ML 5, demand level 4, so RO is 5.*
- *Maximum Level (XL); The XL is required when demand is expected to decrease, e.g, when phasing the weapon systems out. If a maximum level is loaded, the maximum level is compared to the demand level and lower is used as the RO. (XL is lower than ML, even through the names may suggest otherwise.)*
- *Fixed Level (FL); This is a special level for the items that are required to be controled within constant level of demand and supply. FL is applied to the shelf life items and one time business. If a fixed level is loaded, the RO will be fixed at one less than the detail quantity.*
- *Additional Level (AL); In the case of War Reserved Material (WRM), when there are special requirements, the item managers apply the AL. Here, RO is the sum of the original RO and AL.*

3. Selective Inventory Management (SIM)

The Korean Air Force inventory system involves thousands or even million of individual transactions each year. To do their job effectively, material managers must avoid the distraction of unimportant details and concentrate on significant matters. Inventory control procedures should isolate those items requiring precise control from other items that can be controlled with less precision. It is generally uneconomical to apply detailed inventory control analysis to all items carried in inventory. Frequently, a small percentage of inventory items accounts for most of the total inventory value. It is usually economical to purchase a large supply of low cost items and maintain little control over them. On the other hand, small quantities of expensive items are purchased, and tight control is exercised over them. It is often useful to divide inventories into three classes according to dollar volume. This is called SIM or ABC analysis.

The DSM divides their inventories as shown at the table.
Table 2 on page 15 shows ABC inventory classification. The A class is high value items whose dollar volume accounts for 75 through 80 percent of the total inventory, while representing only 15 through 20 percent of the inventory items.

Table 2. THE BASIS OF ABC ITEM GROUP

Group		Annual Demand Dollar Volume
A	1	Above $300,001
	2	$50,001 - $300,000
B		$10,001 - $50,000
C	1	$501 - $10,000
	2	Under $500

The B class is lesser value items whose dollar volume accounts for 10 through 15 percent of the value of the inventory, while representing 20 through 25 percent of the inventory items. The C class is low value but 60 through 65 percent of the inventory items.

Table 3 shows the management status by ABC items. Item managers have to get the approval of the controller by items before issuing and ordering of each item.

Table 3. COMPARISON OF ABC CLASSES

Group	Unit	Degree of Control	Controller	Frequency of Review	Size of IM	Lot Sizes	Size of Safety Stock
A	1	Tight	Dir. of DSM	Continuous	Large	Low	Small
	2		Chief of DIV.				
B		Moderate	Chief of Branch	Occasional	Medium	Medium	Moderate
C	1	Loose	IM	Infrequent	Small	Large	Large
	2		Computer				

E. SUMMARY OF ROKAF INVENTORY PROBLEMS

The review of the Korean Air Force inventory system reveals the following problems :

1. The model does not consider the factor of the source of supply and the budget constraint.

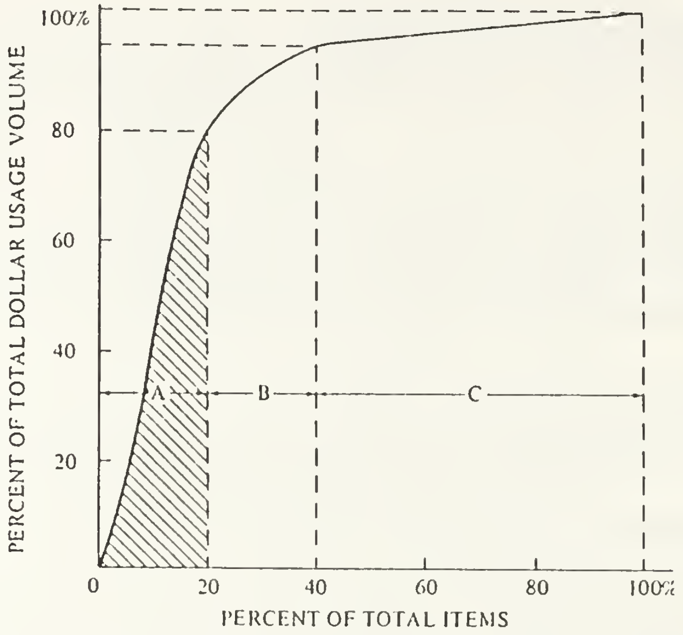

Figure 4. ABC Inventory Analysis

2. The requisition objectives determination lacks the consideration of the stochastic characteristics of the inventory problems.

3. Also, it does not identify the wear-out and regeneration rates which are crucial parameters in the calculation of the RO of the repairable items.

4. It does not consider the variance of demand and ordering and shipping time. So the managers use the model as if it were deterministic. The only consideration for the stochastic nature of demand is found in the safety level quantity. Even there, the actual probability distribution is not considered.

5. The Korean Air Force's model is still based on AFM67-1 which supports base supply level.

6. The model's shortcomings cause excess stock for some items and many stockouts for others.

III. OVERVIEW OF CURRENT INVENTORY THEORY AND U.S MILITARY MODELS

A. CHAPTER OVERVIEW

This chapter introduces models that are represented in the inventory literature, and the U.S military inventory model which the U.S. Air Force and U.S. Navy use to manage the various levels of inventories they own will be discussed. This chapter will first analyze the deterministic version of the EOQ model. Next, an algorithm for determining the backorder cost is presented. Also this chapter explores the stochastic EOQ model with emphasis on determining backorder costs and service levels. The repairable items inventory models in the literature will be presented.

Finally, the U.S. military (U.S. Air Force and U.S. Navy) inventory model will be introduced.

B. LITERATURE REVIEW

1. Economic Order Quantity (EOQ) Models

One of the objectives of inventory management is to minimize the total cost of logistics activities. This can be achieved through use of the EOQ model. Two versions of the EOQ model are explained in this section.

a. The Deterministic EOQ model

First, in the deterministic models, the classical EOQ model is based on the following assumptions. [Ref. 3 : p. 94]

- *The demand rate is known and constant.*
- *The lead time is known and constant.*
- *The entire lot size is added to inventory at the same time.*
- *No stockouts are permitted; since demand and lead time are known, stockouts can be avoided.*
- *The cost structure is fixed; order/set up costs are the same regardless of lot size, holding cost is a linear function based on average inventory and no quantity discounts are given on large purchases.*
- *There is sufficient space, capacity, and capital to procure the desired quantity.*
- *The item is a single product; it does not interact with any other inventory items. (there are no joint orders.)*

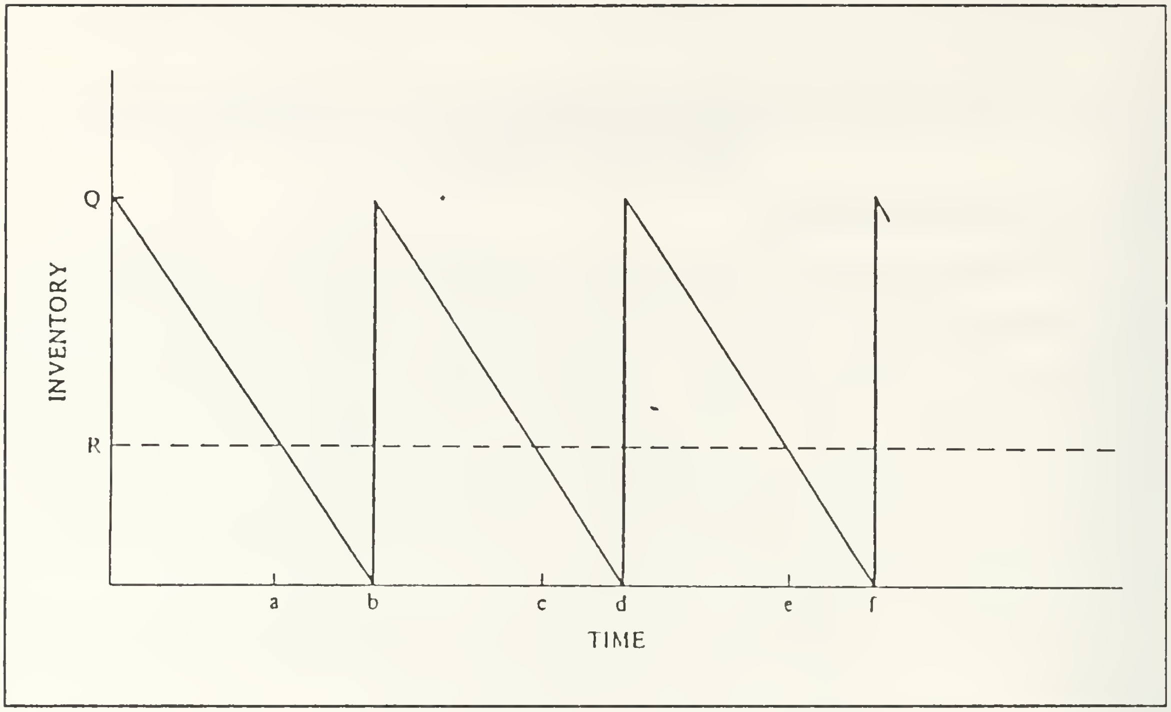

Figure 5. Classical Inventory Model:

R Reorder Point

Q Economic Order Quantity

Figure 5 on page 18 is the idealized situation where Q is the order size upon receipt of an order, the inventory level is Q units. Units are withdrawn from inventory at a constant demand rate, which is represented by the negative sloping lines. When the inventory reaches the reorder point R, a new order is placed for Q units. After a fixed time period, the order is received all at once and placed into inventory. The vertical lines indicate the receipt of a lot into inventory. The new lot is received just as the inventory level reaches zero. The cost formulas associated with the basic EOQ model are:

Total Annual Cost = Purchase Cost + Order Cost + Holding Cost

$$TC = DC + \frac{AD}{Q} + \frac{1}{2} \times QIC$$

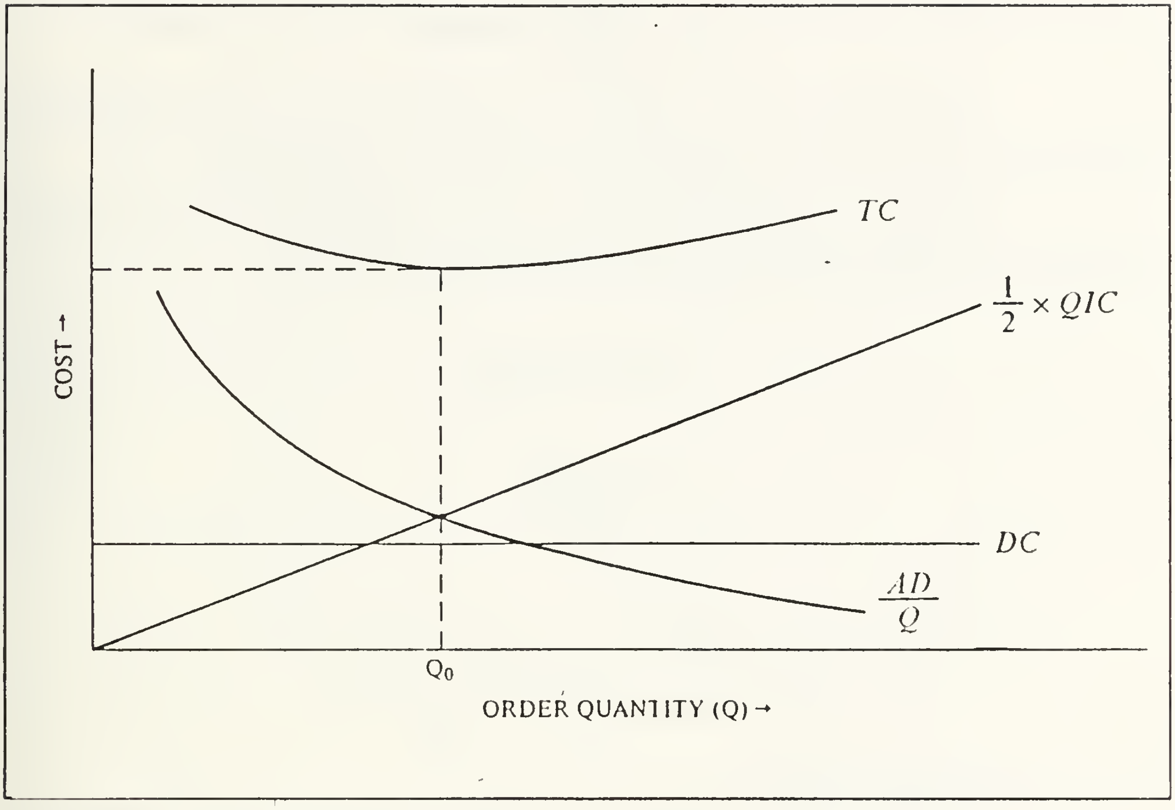

Figure 6. Annual Inventory Costs

where

D = Annual Demand in units.

C = Purchase Cost of an item.

A = Ordering Cost per an order.

I = Annual Holding Cost Rate.

The optional order quantity is equal to the minimum point on the total cost curve on the Figure 6. To obtain the minimum cost lot size (EOQ), take the derivative of total annual cost with respect to the lot size (Q) and set it equal to zero:

$$\frac{dTC}{dQ} = -AD(Q)^{-2} + \frac{IC}{2} = 0$$

$$Q^2 = \frac{2AD}{IC}$$

$$Q = \sqrt{\frac{2AD}{IC}} = EOQ$$

The EOQ results in items with high unit cost being ordered frequently in small quantities; items with low unit cost are ordered in large quantities.

Once the EOQ has been determined, the reorder point (R) and average order interval (T) can be determined by using the following formulas:

$$R = \frac{(D \times \mathrm{LT})}{N}$$

$$T = \frac{D}{Q^*}$$

where

N = the number of operating days per year.

LT = Order and Shipping Time.

b. Backorder Costs

A backorder is an unfilled demand to be filled later. If there were no costs associated with incurring backorders, no inventories would be held. If backorders were very expensive, then very large inventories would be held to ensure against the stockouts. However, there is an intermediate range of backordering cost where it is optional to incur some backorders towards the end of an inventory cycle. If we allow stockouts to occur, the backorder cost must also be included in the basic EOQ model. This model is depicted in Figure 7 on page 21.

All the previous assumptions for the model in Figure 5 on page 18hold true except the stockouts are allowed to occur and all shortages are filled by the next lot quantity shipment. [Ref. 3 : p.95] In this case, the maximum inventory is V units while the size of stockouts (S), is equal to (Q-V)units. The backordering cost per unit/year is K and it is directly proportional to the length of the time delay.

The average holding cost during a single time period (t_1) is:

$$H \times \frac{V}{2} \times t_1 = H \frac{(V)^2}{2D}$$

where H = Holding cost (= I x C)

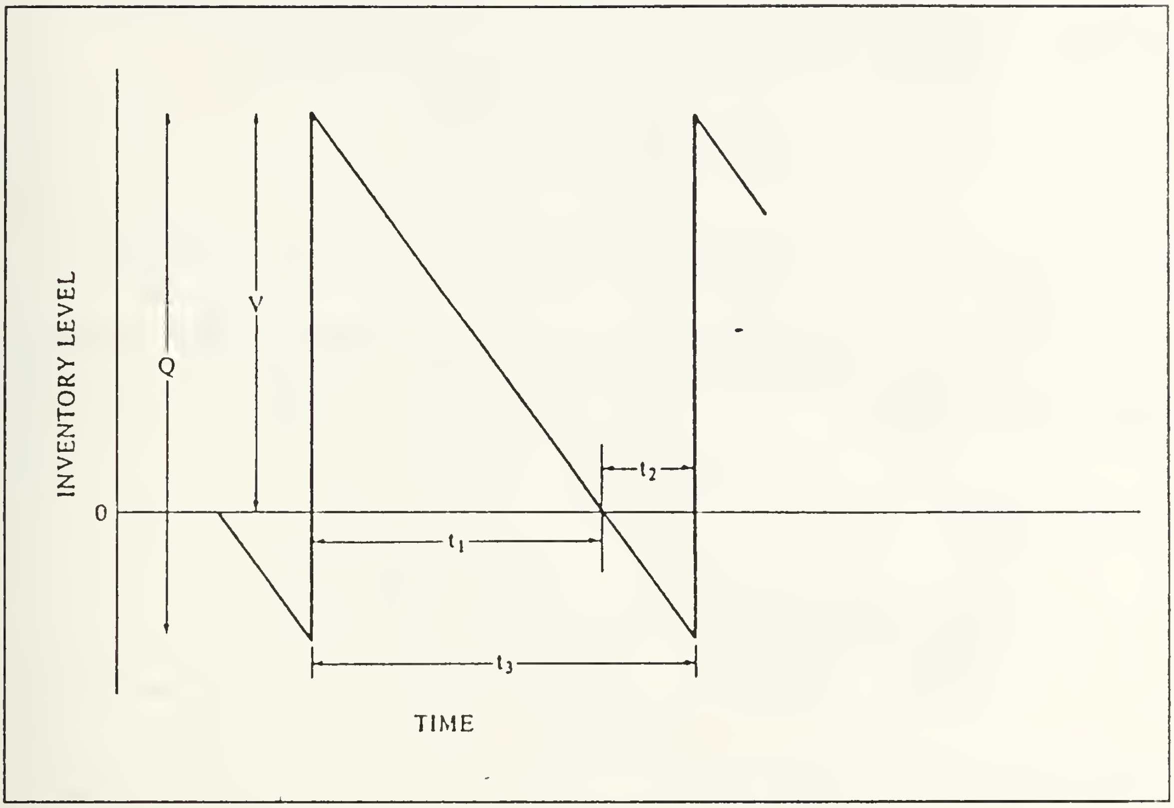

Figure 7. Backordering EOQ Inventory Model:

Q Economic Order Quantity

V Maximum Inventory Level

t_1 Time period during which there is a positive inventory balance

t_2 Time period from stockout to receipt of Q

t_3 Time period from receipt of Q to next reorder of Q

Since the ratio of annual demand to one year is equal to the ratio of maximum inventory to a time period $(\frac{V}{t_2})$, then $t_1 = \frac{V}{D}$

The backorder cost during t_2 is computed as follows:

$$K(Q - V)\frac{t_2}{2} = K\frac{(Q - V)^2}{2D}$$

Therefore, the total cost for one time period of length t_3 is computed as:

$$TC = DC + \frac{DA}{Q} + H\frac{(V)^2}{2D} + K\frac{(Q - V)^2}{2D}$$

By taking the partial derivatives of the total annual cost with respect to Q and V and setting them to zero, the following optimum formulas result:

$$Q = \sqrt{\frac{2DA}{H}} \times \sqrt{\frac{H+K}{K}}$$

$$V = \sqrt{\frac{2DA}{H}} \times \sqrt{\frac{K}{H+K}}$$

The reorder point calculation is modified to subtract the number of back-orders (Q - V) so that:

$$R = D \times \frac{\mathrm{LT}}{N} - (Q - V)$$

where N equals the number of operating days per year.

c. *Stochastic EOQ Model*

In reality, we find few cases where a deterministic EOQ model can be used because we can not fill all of the assumptions of the deterministic model. In the stochastic EOQ model, demand and lead time are treated as random variables while they are known in the deterministic model. The stochastic model assumes that it is possible to state the probability distribution of the demand, and that the average demand, remains approximately constant over time. Lead time can vary because of uncertainty of transportation and order problems, while the pattern of demand over time may be discrete and irregular. Such variations are absorbed by provisions for safety stocks, also referred to as buffer stocks or fluctuation stocks. Safety stocks are extra inventory kept on hand as a cushion against stockouts due to random and unexpected events. Safety stocks have two effects on a firm's cost: it decreases the cost of stockouts, but it increases holding costs. [Ref. 3 : pp. 184-185]

The depth of these safety stocks depends on several factors. [Ref. 4 : p.20]

- *Do stockouts result in lost sales (for profit oriented industries) ?*
- *How expensive are the holding costs for the items ?*
- *What are the variances in the lead time and demand ?*
- *What service level does the organization want to provide ? [Ref. 3 : pp.184-189]*

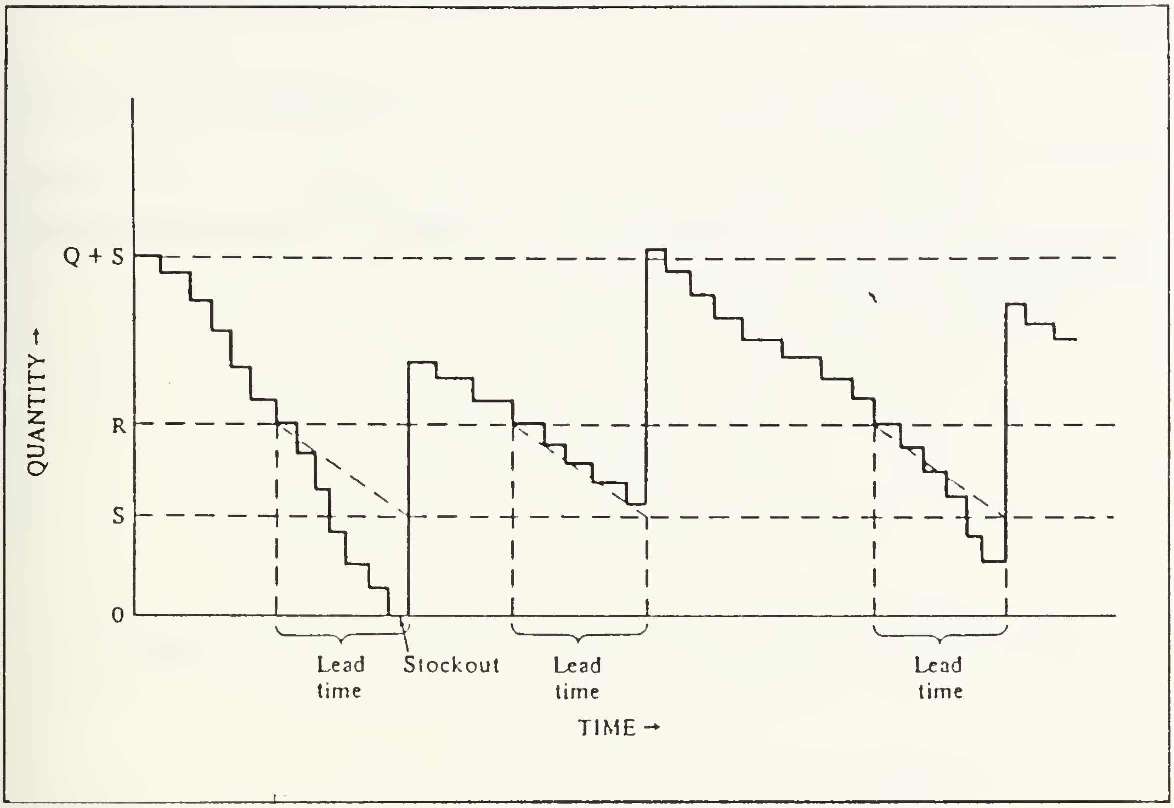

Figure 8. Stochastic Inventory Model:

S Safety Stock

In actual inventory systems, as shown in Figure 8 on page 23, the demand pattern over time will be discrete and irregular. In the first cycle, both the demand pattern and lead time are different with those of the second cycle.

If a stockout condition occurs before replenishment stock arrives, backorders will be filled before new customer demands when the stock does become available. Demand and lead time variations are represented by the normal, Poisson, and negative exponential distributions. The normal distribution has been found to describe many demand funtions at the factory level; the Poisson , at the retail level; and the negative exponential, at the wholesale and retail levels. Of course, these distributions should be verified using a goodness-of-fit test like the Chi-square test of fit before they can be as-

sumed to be reasonable representations of demand or lead time behavior. [Ref. 3 : pp. 191-193]

When demand is treated as continuous, the most frequently used distribution is the normal distribution.

As shown in Figure 9, the probability of a stockout for a given item is simply the probability that the demand during the lead time will exceed the reorder point and is indicated as follows:

For continuous data,

$$P(LTD > R) = \int_R^{\infty} f(LTD)d(LTD)$$

$$E(LTD > R) = \int_R^{\infty} \left(\int_{LTD}^{\infty} f(LTD)d(LTD) \right) D(LTD) = \int_R^{\infty} (LTD - R)f(LTD)d(LTD)$$

For discrete data,

$$P(LTD > R) = \sum_{LTD=R+1}^{LTD_{\max}} P(LTD)$$

$$E(LTD > R) = \sum_{LTD=R+1}^{LTD_{\max}} (LTD - R)P(LTD)$$

where

LTD = Lead Time Demand.

$P(LTD > R)$ = Probability of Stockouts.

R = Reorder Point in units.

f(LTD) = Probability density function of demand during the lead time.

$E(LTD > R)$ = Expected Stockout in units during lead time.

Therefore, with backorders and no loss of sales, the expected safety stock is calculated as

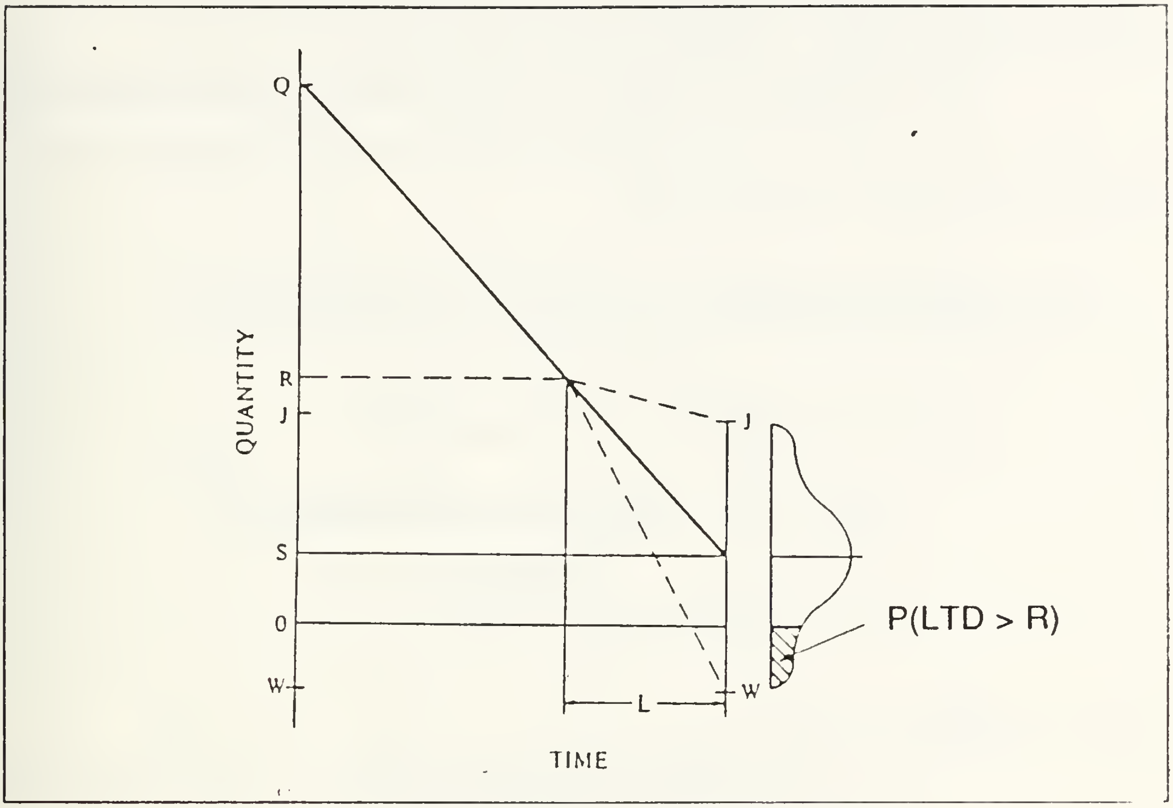

Figure 9. Fit of Normal Distribution to EOQ Stochastic Model:

R	Reorder Point
Q	Order Quantity
L	Constant Lead Time
S	Safety Stock
R - S	Expected Lead Time Demand
R - W	Maximum Lead Time Demand
P(LTD > R)	Probability of a stockout

$$
\begin{aligned}
S &= \int_0^{\infty} (R - LTD) f(LTD)\, d(LTD) \\
&= R \int_0^{\infty} f(LTD)\, d(LTD) - \int_0^{\infty} (LTD) f(LTD)\, d(LTD) \\
&= R - \overline{LTD}
\end{aligned}
$$

where $\overline{LTD}$ is the expected lead time demand, and the number of backorders per lead time if $LTD - R \leq 0$ and LTD - R if $LTD - R > 0$.

The total annual cost of safety stock equals holding cost of the satety stock and stockout cost. When the stockout cost is on a per unit basis, the formula used to determine the total cost of safety stock is:

Annual Safety Stock Cost = Holding Cost + Stockout Cost

$$\begin{aligned} TC &= SH + \frac{BD}{Q}\int_R^\infty (LTD - R)f(LTD)d(LTD) \\ &= H(R - \overline{LTD}) + \frac{BD}{Q}\int_R^\infty (LTD - R)f(LTD)d(LTD) \\ &= H(R - \overline{LTD}) + BDE\frac{(LTD > R)}{Q} \end{aligned}$$

where

TC = Expected annual cost of safety stock,

$R = \overline{LTD} + S$ = Reorder Point in units,

S = Safety stock in units,

H = Holding cost per unit of inventory per year,

B = Backordering cost per unit,

D = average annual demand in units,

Q = Lot size or order quantity in units,

LTD = Lead time demand in units,

$\overline{LTD}$ = Average leadtime demand in units,

f(M) = Probability density function of lead time demand,

LTD - R = Size of stockout in units.

By taking the derivative of the total cost related to the reorder point and setting it equal to zero, the optimum probability of a stockout with a known backorder cost per unit is:

$$P(LTD > R) = P(S) = \frac{HQ}{BD}$$

From this probability and the normal distribution table, we can find the Z-value. Assuming that both follow a normal distribution and are independent, the mean and variance of the demand during the lead time are given by

$$\overline{LTD} = \overline{D} \times \overline{L},$$

$$\sigma^2 = \overline{L} \times \sigma_D^2 + \overline{D}^2 \times \sigma_L^2$$

Then, the combined standard deviation of the lead time is computed as

$$\sigma = \sqrt{\overline{L} \times \sigma_D^2 + \overline{D}^2 \times \sigma_L^2}$$

where

$\overline{D}$ = Mean of the lead time demand,

$\overline{L}$ = Mean of the lead time,

σ_D^2 = Variance of the lead time demand,

σ_L^2 = Variance of the lead time.

With these results, the appropriate amount of safety stock to protect from the lead time demand exceeding Z standard deviation is:

$$S = \sigma \times Z$$

The corresponding reorder point (R), for a given safety stock level of S units, is:

$$R = \overline{LTD} + S$$

2. Fixed Order Interval Systems

The fixed order interval system, also called a periodic inventory system, is based on a periodic rather than a continuous review of the inventory stock position. In this periodic review models, the inventory position is checked at the end of every T time units. If the stock position is below a maximum level called the Requisitioning Objectives (RO), then an order is placed which is large enough to bring the inventory position backup to the level of the RO.

In the deterministic fixed order interval system, the order size is not expected to vary because demand is assumed to be both known with certainty and continuous.

A typical fixed order interval system is shown in Figure 10 on page 28 and Figure 11 on page 29.

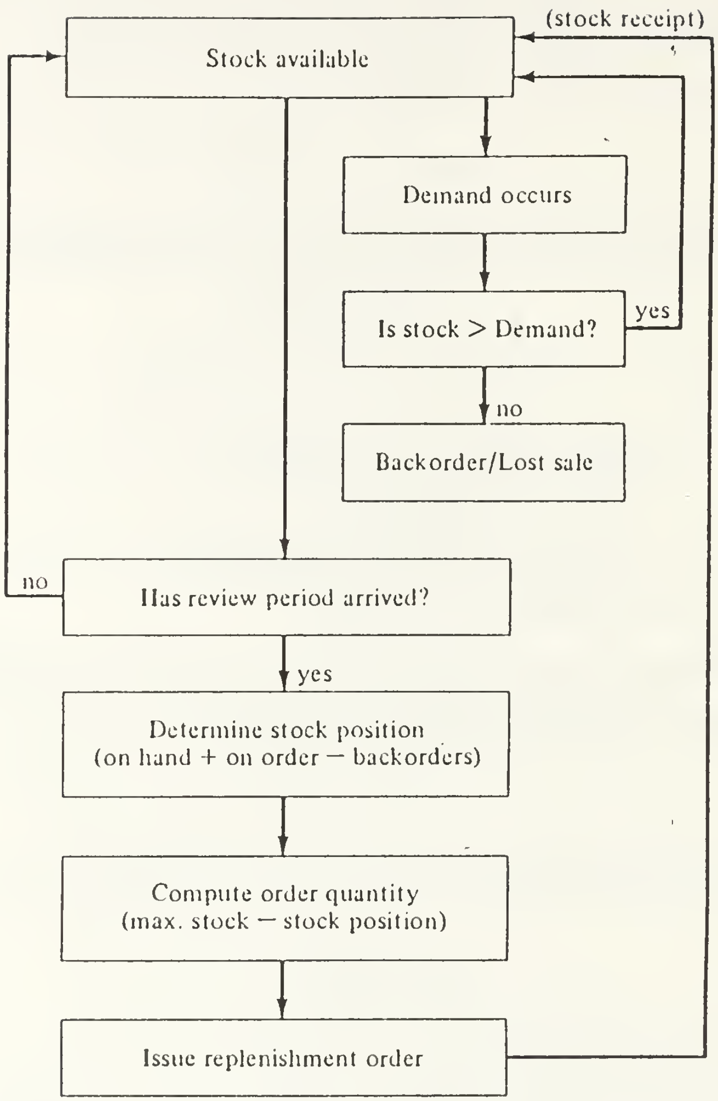

Figure 10. **Fixed Order Interval System**

The basic problem in this model is determining the order interval T and the desired maximum inventory level. When stockouts are not permited, the total annual inventory cost is calculated by the following formula.

Total Annual Cost = Purchase Cost + Order Cost + Holding Cost

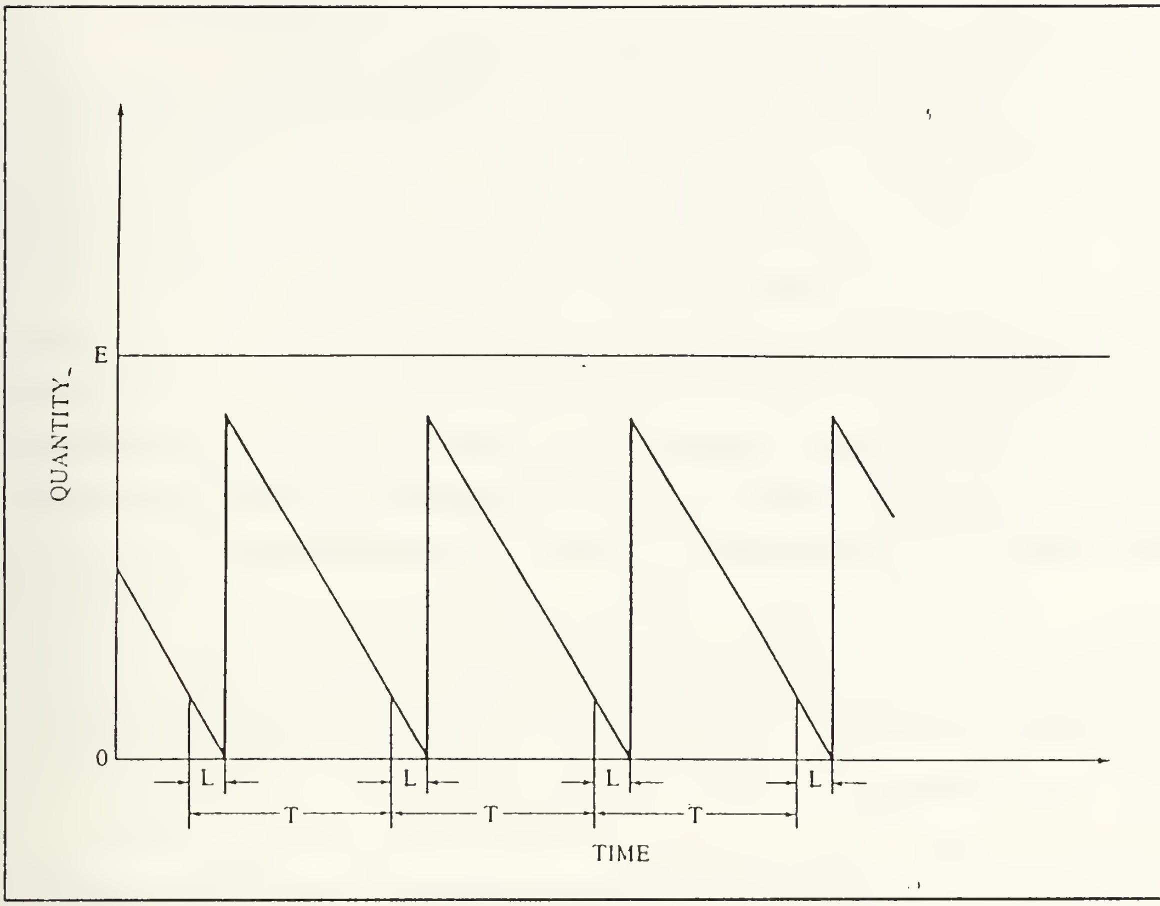

Figure 11. **Deterministic Fixed Order Interval System**

$$TC = DC + mA + \frac{DH}{2m} = DC + \frac{A}{T} + \frac{DHT}{2}$$

where

$m = \dfrac{1}{T}$ = number of orders or reviews per year,

$\dfrac{D}{2m} = \dfrac{DT}{2}$ = average inventory in units,

$T = \dfrac{1}{m}$ = order interval in years.

By taking the first derivative of the total annual cost with respect to the order interval and setting T equal to zero:

$$\frac{dTC}{dT} = \frac{-A}{T^2} + \frac{DH}{2} = 0$$

For T,

$$T_0 = \sqrt{\frac{2A}{DH}} = \text{Economic order interval(EOI) in years}$$

$$m_0 = \frac{1}{T_0} = \sqrt{\frac{DH}{2A}}$$

$$RO = DT + DL = D \times (T + L) = Q + R$$

3. Backordered Centered Models for Repairable Items

a. *Introduction*

As the majority of repairable items are of high value, most of the past studies have focused on the order-for-order (S - 1, S) procurement policy. There have also been efforts to design repairable item models for multi-base and depot applications.

Those are the Base Stockage Model (BSM) developed by the Rand Corpoation in 1965, the Multi-Echelon Technique for Recoverable Item Control (METRIC) model proposed by Sherbrooke in 1967, and a Modified METRIC model (MOD-METRIC) developed by Muckstadt in 1973. These models have the following three common characteristics:

- *These models are based on Palm's theorem shows that, if demands arrive according to a Poisson process,then the number of items in resupply follows a Poisson distributions. [Ref. 5 : p.5]*
- *These models use the expected backorders as a performance measure and it is calculated by the following formula:*

$$E(S) = \sum_{X=S+1}^{\infty} (X - S)P(X|\lambda T)$$

where

S = spare stock = stock on hand + on order + in repair - backorders

X = the quantity of beginning stock demanded,

λ = the mean demand rate,

$P(X|\lambda T)$ = the probability of observing X demands during the time period being measured.

- *These three models represent a steady-state situation, which means the demand rate and its associated variation remain constant over time.*

In this section, the METRIC and MOD-METRIC models are introduced.

b. METRIC Model

A Muti-Echelon Technique for Recoverable Item Control (METRIC) is a mathematical model translated into a computer program capable of determining base and depot stock levels for a group of repairable items. This model is designed for application at the weapon system level, where a particular line item may be demanded at several bases and the bases are supported by one central depot.

This model has three purposes. The first purpose is to determine base and depot stock levels so that the sum of the expected backorders is minimized at all bases having a particular weapon system. Second, the model can be used to determine stock levels for each particular item that minimizes the expected total base backorders. The last purpose of the model is for analysis of system performance.[Ref. 6: p.2]

The METRIC model includes several assumptions as follows:[Ref. 6: pp.6-11)

- *The METRIC is a steady-state model.' The distribution of demand over some future period of interest is stationary.*
- *The model ignores the probability of lateral resupply between bases.*
- *The model implies that there are no condemnations or that the system is conservative.*
- *Depot repair begins immediately when the repairable base turn-in arrives at the depot.*
- *All items have equal essentiality.*
- *Demand from the several bases can be pooled in some manner so that a composite initial estimate of demand per flying hour can be obtained.*

The METRIC model uses a compound Poisson process to explain the demand on the system. Demand for each item is described by a logarithmic Poisson process. The logrithmic Poisson is obtained by considering batches of demand where the number of batches follows a Poisson process and the number of demands per batch has a logarithmic distribution. [Ref. 6 : p.8]

In order to formulate this model, we consider one item i stocked at J bases, with known mean customer arrival rates, $\lambda_j j = 1,2,3,...,j$. When a customer arrives at a base to place one or several demands, he turns in a same number of repairable items. It is assumed that with probability r_j, these units can all be repaired at base level and with probability, $1 - r_j$, they must all be shipped to the depot for repair. Then, the arrivals from base j at the depot described a Poisson process whose mean equals $(1 - r_j)$

times the mean of the Poisson customer arrival process at base j. Where customer rate(λ) equals $\sum\lambda_j(1 - r_j)$.

Suppose f_j is the mean demand per customer at base j. Then, the mean depot demand rate is:

$$\theta = \sum_{j=1}^{J}\lambda_j f_j(1 - r_j) = \sum_{j=1}^{J}\theta_j(1 - r_j)$$

where θ_j = the mean demand at base j .

From the equation of assumption, the expected number of units delayed at the depot at some arbitrary point of time is : [Ref. 6 : p.14]

$$B(S_0|\lambda D) = \sum_{X=S_0+1}^{\infty} (x - S_0)p(X|\lambda D)$$

where

S_0 = depot stock,

X = demands,

D = average depot repair time.

$\lambda = \sum\lambda_j(NRTS_j)$, λ_j
= demand rate during a fixed time period at base j and $NRTS_j$
= percentage of units NRTS at base = $(1 - rsubj)$.

For computing of the average delay per demand, the following formula is applied:

$$\sum_{X=S_0+1}^{\infty} (X - S_0)P\frac{(X|\lambda D)}{\lambda f} = \delta(S_0)D$$

where

$\delta(S_0) = \dfrac{B(S_0\lambda D)}{B(O|\lambda D)}$,

O = average order and shipping time,

D = average depot repair time.

For each level of depot stock, S_0, the expected backorder is:

$$B(S) = \sum_{X=S+1}^{\infty} (X - S)p(X|\lambda T)$$

where

$S = S_j$,

$\lambda = \lambda_j$,

$T = r_j A_j + (1 - r_j)(O_j + \delta(S_0)D)$,

r_j = probability that can be repaired at base j ,

A_j = repair cycle time of base .

Recall that the objective function of METRIC is to minimize total expected backorders at all bases within a given budget constraint. Mathematically, this is represented as follows:

$$\text{MIN} \quad \sum_{i=1}^{n}(\sum_{j=1}^{m} B_{ij}(S_{i0,}S_{ij}))$$

subject to

$$\sum_{i=1}^{n}\sum_{j=0}^{m} C_i S_{ij} \leq M$$

$$S_{ij} \geq 0,\ 1 \leq i \leq n,\ 0 \leq j \leq m$$

where

S_{ij} = the decision variables,

M = budget constraint,

C_i = the cost of item i ,

S_{i0} = the depot stock for item i.

c. *MOD-METRIC Model*

The MOD-METRIC model developed by Muckstadt is a modification of the METRIC model. The METRIC model tended to focus more heavily on inexpensive sub-components because it was able to reduce the backorder level more by buying these items. The MOD-METRIC resolves this problem by establishing an indenture relationship between components and sub-components. The more expensive components of weapon systems, known as Line Replacement Units (LRUs), are made up of sub-

components called Shop Replacement Units (SRUs). When an aircraft has a failed LRU, this LRU is removed at the flight line and taken back to the shop where it is repaired by replacing the defective sub-component with a new SRU.

All of the METRIC assumptions adopt to the MOD-METRIC model except for one. In METRIC model, all items are considered to be equally essential. In MOD-METRIC, this assumption can't be applied due to the different impact on performance of an LRU and a SRU. Also the following assumptions apply to the MOD-METRIC model: [Ref. 4 : p.58]

- *Each LRU failure is due to only one SRU failure.*
- *Each SRU belongs to only one LRU.*
- *LRUs are normally repaired at base level while SRUs are repaired at the depot.*

The algorithm is designed to minimize expected backorders for all end items subject to a dollar constraint on the inventory investments in both LRUs and SRUs. Mathematically, this is: [Ref. 7 : pp.472-475]

$$\mathrm{MIN} \quad \sum_{i=1}^{m} \sum_{X_i = S_i + 1}^{\infty} (X_i - S_i) P(X_i | \lambda T_i)$$

subject to

$$\sum_{i=1}^{m} C_e S_i + \sum_{j=1}^{n} C_j S_{ij} + \sum_{j=1}^{n} C_j S_{0j} + C_e S_0 \leq BudgetConstraint$$

where

S_i = stock level of end items at base i,

C_e = unit cost of an item (LRU),

C_j = unit cost of SRU (module) j,

The difference between METRIC and MOD-METRIC model is the manner in which the average resupply time (T_i) is computed. The METRIC model calculates T_i as :

$$T_i = r_j A_j + (1 - r_j)(O_j + \delta(S_0) D)$$

While MOD-METRIC model represents T_i as:

$$T_i = r_j(R_j + \Delta_j) + (1 - r_j)(D_j + \delta(S_0)D)$$

where

r_j = the probability that a failure isolated to an SRU will be repaired at base,

A_j = average repair cycle time of base j,

O_j = average order and ship time,

$\delta(S_0)D$ = expected backorders over expected daily demand at the depot,

R_j = average repair time at base if SRU_i is present,

Δ_j = average delay in base repair due to the unavailability of a needed SRU.

The MOD-METRIC model is concerned solely with the minimization of LRU backorders subject to a budget constraint. It can be characterized as a multi-item, multi-indenture, multi-location, and multi-echelon model. The model can be available specifically for the management of aircraft engines and their subcomponents.

4. Availability Centered Models for Repairable Items

a. *Introduction*

Availability centered models use an operational availability of aircrafts as a performance measure. These performance measures directly measure the impact of a given stock level and demand rate on the availability of the aircraft. The two primary performance measures used are Not Mission Capable Supply (NMCS) aircraft and Fully Mission Capable (FMC) aircraft. In this section, the Logistics Management Institute (LMI) availability-centered model and the Dyna-METRIC model are addressed. These model are all similar to the backorder centered models in that they incorporate Palm's Theorem.

b. *LMI Avilability Centered Model*

The LMI model was developed for use in conjunction with the metric model to compute the expected backorder reduction for each repairable component. [Ref. 8 : p.8] The LMI availability centered model expected backorders (and expected backorders reductions) into expected NMCS aircraft (and expected NMCS reductions). It can predict an expected number of NMCS aircraft given that an initial number of repairable items exists for each repairable component. [Ref. 4 : p.63]

The basic LMI model assumes as follows: [Ref. 8 : p.12]

- *An aircraft missing a repairable component due to a stockout will be NMCS if the component would cause an NMCS condition in real life.*
- *An aircraft cannot be NMCS unless at least one unit of a NMCS causing component is in need of repair and a spare is not available.*
- *The failure of any single NMCS causing component is independent of the failure of any other component, and is also independent of the operational state of the aircraft.*
- *When more than one unit of any component is installed on an aircraft, the failure of one unit is independent from failures of any of the other like units.*

The objective of the LMI model is to minimize the number of NMCS aircraft given a constraining budget value. The probability that an aircraft is not missing an item(i) is given by the equation:

$$1 - E\frac{B_i}{F}$$

where

$E(B_i)$ = expected number of backorders for item i,

F = fleet size.

If the quantity per aircraft of a particular item (QPA_i) is greater than one, then the formula becomes:

$$1 - \left(E\frac{B_i}{F \times QPA_i}\right)^{QPA_i}$$

The probability that an aircraft is not missing any items is the product sum of the probabilities of that not missing item(i). [Ref. 4 : p.52]

LMI model also allows for a cannibalization policy. This has the net effect of increasing the FMC rate because aircraft that are down can be cannibalized to supply parts to other aircraft and this reduces the number of aircraft that are down. With full cannibalization, the operational rate can be defined as a function of the number of aircraft(M) used as a supply source. With the effects of cannibalization considered, the probability for the expected number of NMCS aircraft is: [Ref. 4 : p. 67]

$$Expected\ NMCS = \sum_{M=0}^{F} \left(1 - \left(\prod_{i=1}^{n}\left(\sum_{X=0}^{S_i + (M \times QPA_i)} P(X|\lambda_i T_i)\right)\right)\right)$$

These measures of availability provides an important step in repairable inventory model evaluation. However, for war planning purposes, LMI model is inadquate.

c. Dyna-METRIC Model

All discussed repairable inventory models have two main deficiencies. One is that the use of expected backorders as a performance measure did not sufficiently indicate how it affected the operational status of the aircraft fleet. The other deficiency is that all modeled a steady-state environment. Consequently, the models would be of little use in a war time period where changing demand rates, repair functions, deployments and other war-time favtors would have a dramatic affect on the inventory system. [Ref. 4 : p.72]

The Dyna-METRIC model was developed to provide a dynamic model that was operational criteria as performance measures. The model can be charaterized as multi-echelon, multi-indenture, multi-item, multi-location and stochastic. It is important to note that Dyna-METRIC sets stockage policy in a dynamic demand environment. That is, it allows a item manager to look at wartime scenarios and determine the effects of inadequate logistical support.

It provides five new kinds of information for logisticians charged with planning and managing support for aircraft components: [Ref. 9 : pp.3-7]

1. Operational performance that enable logisticians to see how all echelons' and functions' local resources and productivity combine to affect overall weapon system support.
2. Effects of wartime dynamics; The model incorporates dynamics for assessing how those echelons and functions would interact in the critical wartime environment, when external demands increase and the logistics system reorganizes to meet those demands.
3. Effects of repair capacity and priority repair; The model forecasts how increased component demands would interact with available repair resources and priority repair, so that logisticians can assess whether the available repair capability would be adequate to achieve the desired operational wartime capability.
4. Problem detection and diagnosis; The model identifies problem components and support processes that cause excessive degradations to wartime capability. So attention and efforts can be focussed on improving support for the most serious problems.
5. Assessments or requirements; the model can either assess existing resources and productivity or it can suggest a cost-effective mix of component spares to achieve a target wartime capacity.

The Dyna-METRIC operates under the following assumptions. [Ref. 9 : pp.31-32]

- *Repair procedures and productivity are unconstrained and stationary (except for the test-stand simulation).*
- *Full Mission Capability (FMC) sortie rates do not directly reflect flight line resources and the daily employment plan.*
- *Component failure rates vary only with user requested flying intensity.*
- *Aircraft at each base are assumed to be nearly interchangeable.*
- *Repair decisions and actions occur when testing is complete.*
- *Component failure rates are not adjusted to reflect previous FMC sortie accomplished.*
- *All components repair processes are identical at all echelons.*
- *No lateral resupply allowed.*

The primary objective of Dyna-METRIC is to avoid the loss of aircraft mission capability due to shortages of recoverable components. The local supply of these components needs to exceed the number of components tied up in the repair and resupply pipelines in order to achieve this goal. [Ref. 10 : p.3]

The Dyna-METRIC portrays component support processes as a network of pipelines through which aircraft components flow as they are repaired or replaced. Figure 12 on page 39 represents each of those processes as an arc which may be conceived as a segment of a pipeline containing components flowing in the direction indicated by the arrow. The model forecasts the quantity of each component in the repair and resupply pipelines based on the components interaction with the operational war time demand. These pipeline quantities are combined and the effect on aircraft availability and sortie rate are estimated by using statistical methods.

A key nature of the Dyna-METRIC model is its ability to deal directly with the transient demands placed on component repair and inventory support caused by a dynamic environment. It includes a set of analytical mathematical models of components (LRUs) and subcomponents (SRUs) and multiple echelons of repair capability.

The following section reviews those results and describes how multiple echelons, multiple indentures, and requirements optimization can be incorporated in a dynamic model.

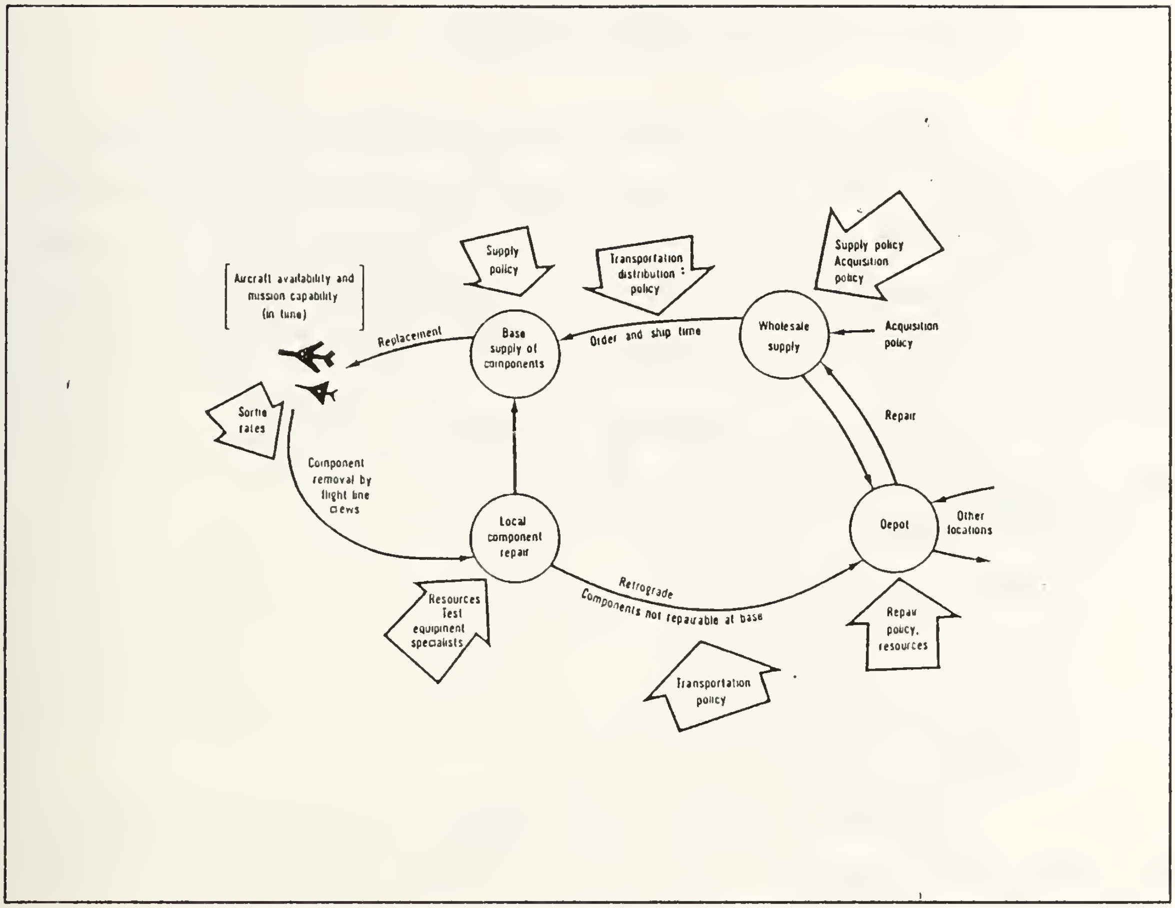

Figure 12. **Component Repair and The Readiness Assessment Problem**

(1) Time-dependent Pipelines and Probability Distributions Under classical steady-state theory, the average number of components in the repair pipeline will be

$$\lambda_{ss} = \bar{d}T$$

where

$\bar{d}$ = the average daily demand rate,

T = average repair time.

With the further assumption that demand has a Poisson probability distribution, the probability that there are K components in the pipeline at any point in time is given by

$$P(K \text{ in pipeline}) = \frac{\lambda_{ss}^{K} e^{-\lambda}_{ss}}{K!}$$

Unfortunately, operations and logistics seldom achieve steady-state, especially in wartime. Then, Hillestad and Carrillo demonstrated how Palm's result could be extended to the dynamic wartime situation. As shown in Figure 13, in their Dyna-METRIC formulation, the time-dependent component removals due to operational demands are combined with the time-dependent repair capability. [Ref. 9 : pp.12-13]

In the dynamic model used in Dyna-METRIC model, the daily demand rates, d(t), are a function of time so that [Ref. 10 : pp. 8-23]

d(t) = failures per flying hour
x flying hours/sortie at time t
x number of sorties per day per aircraft at time t
x number of aircraft at time t
x quantity of the component on the aircraft
x percentage of aircraft with the component

In place of a constant average repair time, T, the dynamic model uses the probability that a component entering repair at time S in repair at time t. This probability function, F(t,S), is called the repair function. It is defined as follows

F(t,S) = Prob(component entering at S is still in repair at t)
= Prob(Repair time > t-s when started at S)

Consider only those components that arrived in an interval of time, ΔS , centered at time S. The expected number in the repair pipeline at time t is then given as follows:

$$\Delta\lambda(t,S) = d(S) \times F(t,S) \times \Delta S$$

where

$\Delta\lambda(t,S)$ = expected number of components in the repair pipeline at time t that arrived during the interval around S,

d(S) = daily failure rate at time S,

F(t,S) = probability of component not out of repair by time t,

ΔS = interval of time centered at S.

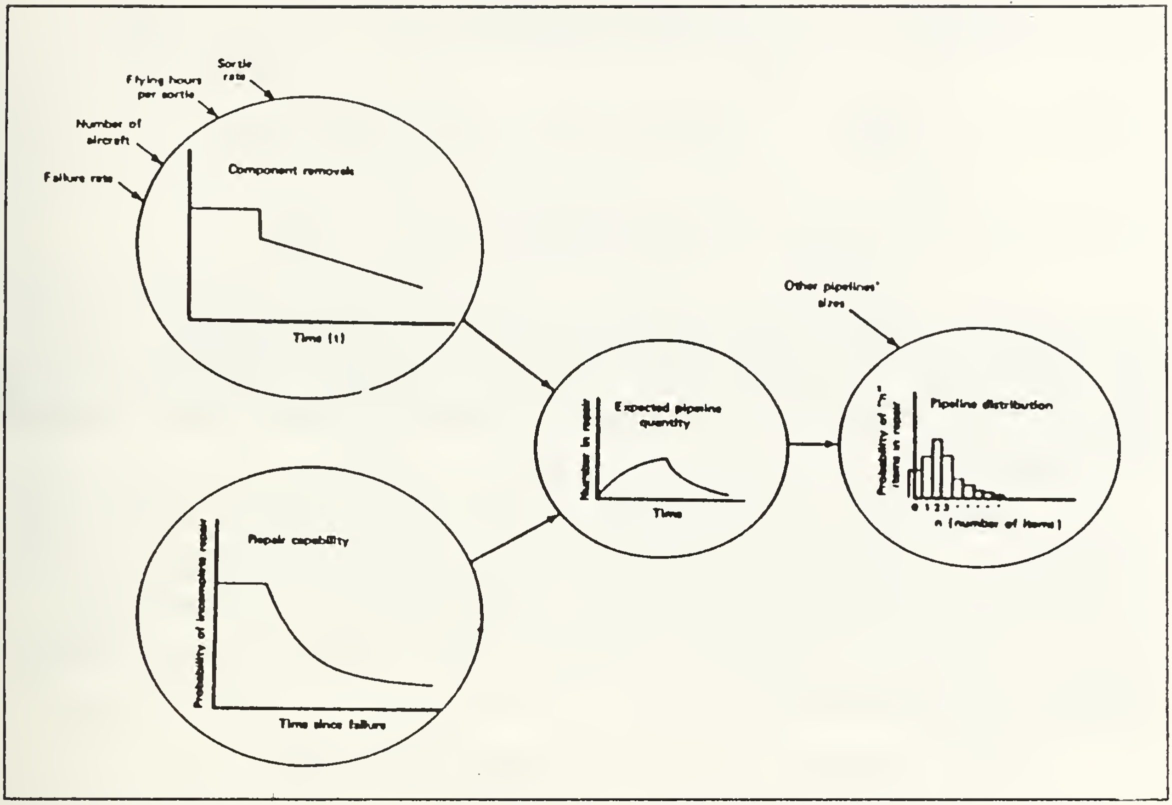

Figure 13. Computing Pipelines

If we suppose that the number of failures arriving in the interval ΔS is independent of the number of failures arriving in similar intervals centered at other times other than S and the repair probability function is independent of the probability distribution generating the demand rate. Then:

$$\lambda(t) = \sum_{S \leq t}^{\infty} \Delta\lambda(t,S) = \sum_{S \leq t}^{\infty} d(S)F(t,S)\Delta S$$

If we make d(S) small,

$$\lambda(t) = \int_0^t d(S)F(t,S)dS$$

Therefore, under the additional assumption that the component failure probability distribution is poisson, $\lambda(t)$ is the mean nonhomogeneous (time varying) poisson process. That is, the probability of K components in repair at time t is:

$$P(K) = \frac{\lambda(t)^K e^{-\lambda}(t)}{K!}$$

where

$$\lambda(t) = \int_0^t d(S)F(t,S)dS$$

Peacetime or steady-state pipeline quantity preceding t = 0 can be considered by computing $\lambda(0)F(t,0)$, the quantity of the pipeline remaining at time t. If the variance to mean ratio is greater than 1, the model follow the negative binomial distribution process.

(2) Time-dependent Component Performance Measure Combining the time-dependent average component pipeline with the supply levels at the same instant of time allows the determination of various measures describing the availability or shortages of individual components at the aircraft. The components measures typically computed by this model are:

R(t) = Ready rate at time t; the probability that an item observed at time t has no backorders,

FR(t) = Fill rate at time t; the probability that a demand at time t can be filled immediately from stock on hand,

EB(t) = Expected backorders; the average number of shortages of a component at time t,

VBO(t) = Variance of the backorders; a measure of the random variation of backorders,

DT(t) = Average cumulative demands by time t .

The ready rate is computed by

$$R(t) = \sum_{K=0}^{S(t)} P(K|\lambda(t))$$

The fill rate is given by

$$FR(t) = \sum_{K=0}^{S(t)-1} P(K|\lambda(t))$$

Expected backorders are given by

$$EB(t) = \sum_{K=S(t)+1}^{\infty} (K - S(t))p(K|\lambda(t)) = \lambda(t) - S(t) + \sum_{K=0}^{S(t)} (S(t) - K)P(K|\lambda(t))$$

The variance in backorders is given by

$$VB(t) = \sum_{K=S(t)+1}^{\infty} ((K - S(t))^2 P(K|\lambda(t)) - (EB(t))^2)$$

(3) Time-dependent System Performance Measures Dyna-METRIC also forecasts the effect of component shortages (due to shortage of spares, inadequate component-repair capability, etc.) on the number of mission-capable aircraft and consequent ability to generate mission. The average total number of backorders is a useful system measure that describes the total number of holes in aircraft. This measure include the following:

- Average number of systems NMC(not mission capable) without cannibalization, EN(t).
- Average number of aircraft NMC with an instantaneous cannibalization policy, $EN_c(t)$.
- Total expected backorders.
- NMC with partial cannibalization.
- Probability of meeting aircraft missions.
- The expected number of mission demands met, given K non-mission-capable aircraft.
- The probability distribution of the number of mission demands met.

(4) An Indenture Model for Time-dependent Pipelines Dyna-METRIC is a multi-indenture model that considers the impact of subcomponents (SRUs) on assemblies (LRUs). The input to the computer model identifies the indenture relationship between LRUs, SRUs and sub-SRUs. Dyna-METRIC computes expected pipeline quantities for each LRU, SRU and sub-SRU at the base, the centralized intermediate repair facility (CIRF), and depot levels. The model uses a building block approach to determine the overall LRU pipeline.

(5) Time-dependent Optimal Determination of Spare Parts To meet an operational objective, the Dyna-METRIC model permits the determination of spare parts required to satisfy a given level of aircraft availability. The fact that pipelines have time-dependent probability distributions means that the optimal mix of spare components at one point in time may not be an optimal mix at another. Thus, the approach

to take is to compute, for each time of interest, the marginal increase in spare parts to achieve a given capability over those already input or determined for a previous time.

The determination of supply levels within Dyna-METRIC is separated into four phases, dealing with: spare parts to overcome queueing in test facilities, spare parts for higher echelons, spare parts for subassemblies, and spare parts of major assemblies at the squadron.

In this section, to achieve the goal of study, only supply levels for higher echelons are discussed. That is, this subsection addresses the problem of providing spares to a higher echelon facility serving several squadrons at different locations.

For the centralized supply, Hillestad employed a heuristic approach as follows: [Ref. 10 : pp.71-76]

1. Start with a given level of supply at the higher echelon, say S_i^{co} .
2. Determine the spare parts level for component i (S_i) at the squadrons (after computing the effect of central system shortages using S_i^{co}).
3. Determine an appropriate set of Lagrange multipliers given the solution in step 2.
4. Determine the supply level, S_i^c, at the higher echelon given the multipliers and the S_i from step 2.
5. Redetermine S_i at each squadron given the new value of central system supply.

The overall problem to be solved is

$$\text{MIN} \quad \sum_{i=1}^{K} C_i S_i + \sum_{i=1}^{K} C_i S_i^c$$

subject to

$$\Pi P_i^K(Q_i K_{N,} S_i^K,\ S_i^c) \geq \alpha \text{for all } K \text{ locations served}$$

$$S_i^{K,} S_i^c \geq 0 \text{for all } K \text{ and } i$$

C. U.S. MILITARY INVENTORY MANAGEMENT SYSTEM

1. U.S. Air Force Inventory System

U.S. Air Force inventory system had an important effect on the Korean Air Force inventory system. In order to establish the model, the predecessors of Korean Air Force Inventory Managers referred to the U.S. AFM67-1 which is Standard Base Supply System (SBSS). This section reviewes both SBSS and the U.S. AFLC Inventory System.

a. Standard Base Supply System (SBSS)

The SBSS is an automated inventory accounting system designed to control U.S. Air Force supply functions. The system is characterized as a multi-item, single-echelon, continuous review inventory system with stochastic, multiple unit demands, backordering and an annual budget constraint. [Ref. 4 : p.28]

The SBSS employs two versions of the classical EOQ inventory model formula. One version uses to the local purchase items and the other is applied for the non-local purchase items.

The objective of the formula is the same as the classical EOQ model. Table 4 shows the cost applied.

Table 4. THE ORDER AND HOLDING COST RATE OF USAF

Class	Local Purchase	Non-local Purchase
Order cost	$19.94	$5.20
Holding cost rate	15 percent	15 percent

Using these constant values, the resulting Base Supply formulas become: [Ref. 11 : pp.3-14]

For local purchase,

$$EOQ = \frac{16.3 \times \sqrt{DDR \times 365 \times \text{Unit Price}}}{\text{Unit Price}}$$

For non-local purchase,

$$EOQ = \frac{8.3 \times \sqrt{DDR \times 365 \times \text{Unit Price}}}{\text{Unit Price}}$$

Where DDR is the Daily Demand Rate.

The reorder point (R) is computed by adding the order and shipping time (OST) quantity to the safety level quantity (SLQ).

The OSTQ and SLQ are calculated as follows:

$$OSTQ = DDR \times OST$$

$$SLQ = C \times \sqrt{OST \times VOD + DDR^2 \times VOO}$$

where

C = selected service level factor that is the same as the value Z we extract from the normal distribution table,

$$\text{VOD (Variance of Demand)} = \frac{\sum Demand^2 - \frac{(\sum Demand)^2}{n}}{n}$$

n = number of days since date of first demand (If $n < 180$, 'use' 180),

$$VOO\text{(Variance of O\&ST)} = \frac{\sum FI \times MI^2 - \frac{(\sum FI \times MI)^2}{n}}{n}$$

FI = number of receipts reflected in each segment of the routing identifier record, frequency distribution table,

MI = Midpoint, in days, of each segment of the routing identifier record, frequency distribution table,

n = number of receipts.

Therefore

$$RO = EOQ + O\&STQ + SLQ + 0.999$$

For computing of repairable item's RO, they use the formula as follows:

Repair Cycle Demand Level (RCDL)

= Repair Cycle Quantity (RCQ)

\+ Order and Ship Time Quantity (O&STQ)

\+ NRTS/Condemned Quantity (NCQ)

\+ Safety Level Quantity (SLQ)

\+ a half adjust factor of 0.5 if the item unit price (IUP) is $750.01 or greater, or 0.9 if the IUP is $ 750.00 or less.

where

$$RCQ = DDR \times \text{Percent of Base Repair}(PBR) \times RCT$$

$$O\&STQ = DDR \times (1.00 - PBR) \times O\&ST$$

$$NCQ = DDR \times (1 - PBR) \times NCT$$

$$SLQ = C\sqrt{3 \times (RCQ + OSTQ + NCQ)}$$

Table 5 shows how to determine the C factor.

Table 5. C FACTOR OF USAF

Standard Deviation (C factor)	Percentage of INV cycle
1	84
2	97
3	99

b. AFLC Inventory Model

The Air Force Logistic Command (AFLC) has a management objective to ensure maximum results in terms of supply availability and economy. AFLC manages its EOQ items through five Air Logistics Centers (ALCs) by using the DO62 EOQ Buy Budget Computation System. The DO62 EOQ Buy System is based on a periodic inventory review which is updated four times a month. Inventory items are divided into the Supply Management Codes (SMGC) which dictate how the items are managed and the degree of management indensity required. [Ref. 12 : p.12] The EOQ formula used by AFLC is listed in AFLCR57-6 and is the same classical EOQ model stated at section A in this chapter.

The annual demand is computed by using actual unit prices and program monthly demand rate (PMDR).

The safety level (SL) for any EOQ item is determined by the formula:

$$SL = K\theta$$

where K is the safety factor in terms of number of standard deviations allowed while θ is the standard deviation of lead time demands.

The computation of θ is: [Ref. 12 : p. 80]

$$\theta = (PPR)^{0.85}(0.5945)MAD(0.82375 + 0.42625\mathrm{LT})$$

where

PPR = Peacetime Program Ratio. A ratio used to calculate future inventory needs,

MAD = Mean Absolute Deviation. The difference between a quarter s forecasted demand and the actual average,

LT = Lead Time. A function of PMDR, administrative, and production lead times,

0.5774 = Constant which converts the mean absolute deviation from a quarterly to a monthly value,

0.82375 and 0.42625 = These are constants which expresses the MAD and over lead time and recognizes that a particular month's demands are influenced by a previou's month's demands.

The standard deviation safety factor (K) is computed as [Ref. 12 : p.80]

$$K = -0.707 \ln\left(\frac{\sqrt{2}\,(H)(2)(UC)}{\frac{\lambda}{\sqrt{R}}(Q)(1 - (\exp\frac{\sqrt{2Q}}{Q}))} \right)$$

where

H = Holding Cost,

Q = EOQ,

UC = Actual Unit Cost,

R = Average Requisition Size

λ = Implied shortage factor that is a mathematical expression used to adjust the safety level in order to meet budget constraints.

For the management of repairable items, AFLC is using the Dyna-METRIC model discussed in previous section [Ref. 4 : p.72]

2. U.S. Navy Inventory Model

a. Introduction

Inventories are maintained to support two functions in the U.S.Navy: peacetime operations and providing an adequate supply of war reserve material. The three levels of peacetime inventory are called wholesale, retail intermediate and retail consumer. Peacetime Operating Stock (POS) as defined by DOD Directive 4140.1 is simply material designated to meet peacetime force material requirements. [Ref. 13 : pp.13-14]

Wholesale supply support provides back up or "systems" stock of repairable and consumable items for the retail levels. At present the retail levels use models such as AVCALs (Aviation Coordinated Allowance Lists) and COSALs (Coordinated Shipboard Allowance Lists). These are stocks of spare secondary items designed to provide sufficient support for a ship deployment period of, say, 90 days. Whenever an item is used by a ship or a squadron, a requisition is immediately submitted to the

wholesale system for a replacement. Thus, the COSALs and AVCALs serve only as emergency protection. [Refs. 14 : pp.1-2 and 15 : pp.1-10]

Table 6 summarizes the models that are being used for provisioning in the U.S. Navy.

Table 6. U.S. NAVY INVENTORY MODEL BY SUPPLY LEVEL

<table>
<tr><th colspan="3" rowspan="2">Supply Level</th><th colspan="2">Initial Provisioning</th><th rowspan="2">requirement Determination</th></tr>
<tr><th>Budget</th><th>Actual Range and Depth</th></tr>
<tr><td rowspan="3">Wholesale</td><td colspan="2">ASO</td><td>DODI4140.42 COSDIF (UICP D54)</td><td>ASO Optimized Provisioning Model</td><td rowspan="3">Mathematical models used in the Uniform Inventory Control Programs</td></tr>
<tr><td colspan="2" rowspan="2">SPCC</td><td rowspan="2">DODI4140.42 COSDIF (UICP D55)</td><td>Electronic: Variable Threshold Model (UICP D55)</td></tr>
<tr><td>Exploder: Partly mannual using LAPL</td></tr>
<tr><td rowspan="6">Retail</td><td colspan="2" rowspan="2">Intermediate Load List</td><td colspan="2">Fleet Issue Load List (FILL)- Range Constraints-Math Model</td><td rowspan="6">Retail Inventory Management and Stockage Policy (RIMSTOP), Variable Operating and Safety Level Inventory Models (VOSL), Economic Range Model (ERM)</td></tr>
<tr><td colspan="2">Tender and Repair Ship Load List (TARSLL)-Range Constraints
-TARSLL Variable Protection Model</td></tr>
<tr><td rowspan="4">Consumer Allowance List</td><td rowspan="2">ASO</td><td colspan="2">ASHORE: Allowance Requirements Register (ARR) Model (D53)
- Shore Consolidated Allowance List (SHORECAL)</td></tr>
<tr><td colspan="2">AFLOAT: ARR Model(D53) - Aviation Consolidated Allowance List(AVCAL)</td></tr>
<tr><td rowspan="2">SPCC</td><td colspan="2">ASHORE: Coordinated Shore Based Allowance List(COSBAL)
- MODFLSIP, TRIDENT, MCO, ACIM</td></tr>
<tr><td colspan="2">AFLOAT: Coordinated Shipboard Allowance List(COSAL)
- MODFLSIP, TRIDENT, MCO, ACIM</td></tr>
</table>

This section introduces the existing wholesale requirement determination model used by SPCC. It is more mathematically sophisticated than the ASO model and it is also easier to understand. Basically, the UICP inventory models attempts to minimize the sum of three variable costs: ordering cost, holding cost, backorder cost.

b. Assumptions

The development of the UICP formula for inventory levels follows the approach used by Hadley and Whitin in their book. [Ref. 16 : pp.162-165]

The key assumptions underlying the UICP models include:

- *A continuous review system. Wholesale inventory levels requirements and assets are known by the Inventory Control Point (ICP) at all times.*
- *Steady state environment. The key charateristic of the items managed by the ICP are constant over the forecast period. Those are the forecasted average values, variances of the random variables of the rate of customer demand, procurement leadtime, depot repair times, depot repair survival rate and the rate of carcass returns.*
- *To eliminate difficulties in modeling large asset deficiencies to the reorder level or the repair level at the instant of procurement or repair review, it is assured that an order for procurement or repair is placed when the assets reach the reorder level or the repair level and that customer demand and carcass returns do not occur in more than one unit transactions.*
- *The unit procurement cost or repair cost of an item is independent of the magnitude of order quantity or repair quantity.*
- *The cost of a backorder and the time-weighted cost of a backorder can be accurately quantified.*
- *The reorder level and repair level are always non-negative.*
- *The cost to hold one unit of stock in the inventory is proportional to the unit cost of the item.*
- *No interaction exists among families of items or individual nonfamily items or both.*

c. UICP Consumable Procurement Model

The UICP consumable procurement model, based on DODI4140.39, is the minimization of the annual variable cost equation composed of the sum of an ordering cost, a holding cost, and a shortage cost. In this model, the variable cost equation is equal to: [Ref. 13 p.3-A-4-7]

$$TVC = \sum_{i=1}^{N} \left(\frac{4D_i}{Q_i} \right) A + \sum_{i=1}^{N} \left(R_i + \frac{Q_i}{2} - L_i D_i + B_i \right) IC_i + \sum_{i=1}^{N} \left(\frac{B_i}{S_i} \right) \lambda E_i$$

where

TVC = total annual variable costs,

i = item index,

N = total number of items in inventory,

D = quarterly demand,

Q = order quantity,

A = administrative cost of placing an order on procurement plus the manufacturer's production set up cost,

R = reorder level,

L = procurement lead time,

B = expected number of units of stock backordered at any random point in time,

I = inventory holding cost rate; a rate per unit cost per year representing the costs of storage obsolescence and time preference,

C = unit cost,

λ = shortage cost of one requisition backordered for one year,

E = military essentiality.

The formulation for the expected number of stock backordered at any point is provided in DODI4140.39 as follows:

$$B = \frac{1}{Q}\int_R^{\infty}(X - R)(F(X + Q;L) - F(X;L))dX$$

where

X = demand random variable,

F(;) = cumulative probability distribution of lead time demand.

To simplify the solution development, the summation signs are dropped and the partial derivatives of the variable cost equation are taken with respect to Q and R and set to Zero. That is,

$$\frac{\partial(TVC)}{\partial Q} = 0 = \frac{-4AD}{Q^2} + \frac{IC}{2} + (IC + \lambda\frac{E}{S})(\frac{\partial B}{\partial Q})$$

$$\frac{\partial(TVC)}{\partial R} = 0 = IC + (IC + \lambda\frac{E}{S})(\frac{\partial B}{\partial R})$$

In solving the partial derivatives of B,

$$B = \frac{1}{Q}\int_R^{R+Q} b(t)dt$$

where

b(t) = the expected number of units backordered a lead time after the inventory position equals t,

Q = order quantity,

$b(t) = \int_t^{\infty}(X - t)f(X)dX$, and
f(X) is the probability distribution of lead time demand.

By using the rules for the derivatives of products and quotients and Leibnitz's rule for differentiation of integrals

$$\frac{\partial B}{\partial Q} = \frac{b(R+Q) - B}{Q}$$

$$\frac{\partial B}{\partial R} = \frac{1}{Q}(b(R+Q) - b(R))$$

The expected number of units backordered in an order cycle is the probability of being out of stock at any random point in time (P_{out}) times Q.

Thus,

$$B = \frac{1}{2}(P_{out}\frac{Q}{D})(P_{out}Q) \div \frac{Q}{D} = (P_{out})^2(\frac{Q}{2})$$

Substituting in the partial derivatives and collecting terms, the solution is :

$$Q = \sqrt{\frac{SDA}{IC(1 - P_{out})}} = \frac{Q_w}{\sqrt{1 - P_{out}}}$$

where Q_w is the symbol for the Wilson EOQ formula.

Q is constrained to be no greater than $\sqrt{2}\,Q_w$.

The probability of being out of stock at any random point in time is:

$$P_{out} = \frac{1}{Q}\int_R^{\infty}(F(X+Q;L) - F(X;L))dX = \frac{SIC}{SIC + \lambda E} = \frac{DIC}{DIC + \lambda FE}$$

where

F = average requisition frequency forecast,

S = average requisition size and assumed to be (D/F).

At this point the reorder point R can be found by using an iterative method.

d. UICP Depot Level Repairables (DLRs) Procurement Model

This model is somewhat similar to the UICP model for consumables. Notable differences are the lack of time-weigting of backorders and the inclusion of the receipt of Ready-For-Issue (RFI) assets from a repair process in the DLR model.

the total variable cost equation for this model is basically to orther models. Where

G = quarterly requisition of ready for issue assets from the repair process,

T = repair cycle time,

B = expected number of units on backorder at any random point in time.

B_{2i} = the expected number of requisitions,

λ_1 = shortage cost per requisition backordered,

By setting to zero the partial derivatives with respect to Q and R. then solving for Q. the results:

$$Q = \sqrt{\frac{8(D-G)(A + \frac{\lambda_1 E}{S}\int_R^{\infty}(X-R)f(X; L)dX)}{IC}}$$

UICP approximates Q by using a variation of the economic order quantity formula:

$$Q = \sqrt{\frac{8(D-G)A}{IC}}$$

Collecting terms in $\hat{c}\,\frac{(TVC)}{\hat{c}}\,R$ and substituting $\frac{D}{F}$:

$$RISK = \int_R^{\infty} F(X; L)dX = \frac{QICD}{QICD + 4\lambda_1 EF(D-R)}$$

Because the expression $\int_R^{\infty} f(X, L)dX$ is the cumulative distribution for lead time demand, the shaded area under the normal curve in Figure 14 on page 54 represents the probability of demand exceeding the reorder point in an order cycle, this is the quantity called RISK.

e. UICP Depot level Repairables Repair Model

This model is a requisition short model like the DLR procurement model; the time horizon of the repair problem is a depot level turnaround time.

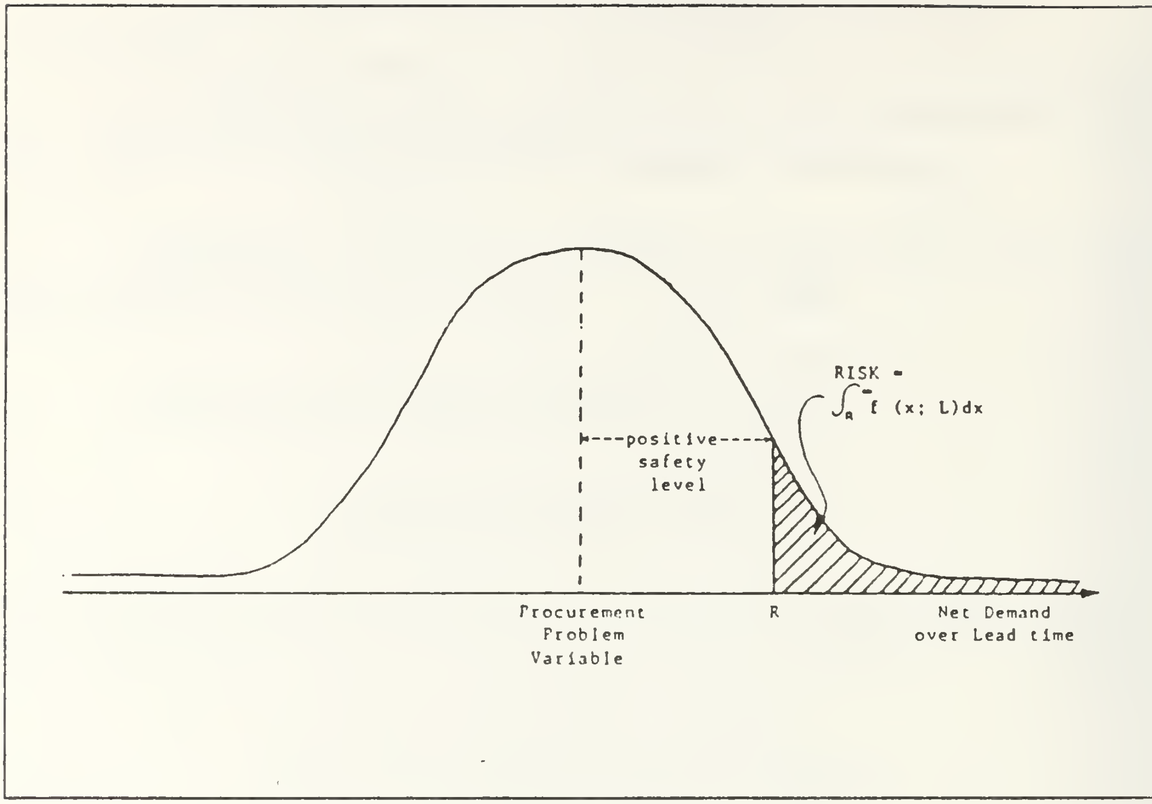

Figure 14. Lead Time Demand and Risk

The difference between the repair cycle time of the DLR procurement model and the depot level turnaround time of this model is shown in Table 7.

Table 7. COMPARISON OF REPAIR TIME FACTORS

Times Interval between Runing of Repair schedules (1)	Shipment time collection point TIR activity to a repair activity (1)
	ICP Admin time to prepare schedule (1)
	Time from issuance of BSS card to induction by repair activity (2)
	Time from indution by repair activity until pick up in RFI condition (3)
	Depot level turn around time (4)
Repair Cycle Time (5)	

Total variable cost equation for the repair model is:

$$TVC_2 = 4 \min \frac{(D, G)}{Q_2} A_2 + I_2 C_2 (\frac{Q_2}{2} + R_2 - DT_2 + B_3) + (\lambda_2 E)(\frac{4 \min(D, G)}{Q_2})B_4$$

where

Q_2 = repair quantity,

A_2 = administrative costs of placing a repair order plus the set up cost for the repair time,

I_2 = repair inventory holding cost rate,

C_2 = repair price,

R_2 = repair level,

T_2 = depot level turnaround time,

B_3 = expected number of units backordered at any random point in time,

λ_2 = repair shortage cost per requisition backordered,

B_4 = expected number of requisitions backordered in a depot level turnaround time.

As with the previous models, by setting the partial derivatives to zero and solving $Q_2 \wedge R_2$:

$$Q_2 = \sqrt{\frac{8 \min(D, G)(A_2 + \lambda_2 E \frac{F}{D} \int_{R_2}^{\infty} (X - R_2) f(X; T_2) dX)}{I_2 C_2}}$$

$$\int_{R_2}^{\infty} f(X; T_2) dX = \frac{Q_2 I_2 C_2 D}{Q_2 I_2 C_2 D + 4\lambda_2 EF \min(D, G)}$$

What is implemented in UICP for Q_2 is:

$$Q_2 = \sqrt{\frac{8 \min(D, G) A_2}{I_2 C_2}}$$

For the solution to R_2, UICP uses

$$\text{Repair Risk} = \int_{R_2}^{\infty} f(X; T_2) dX = \frac{Q_2 I_2 C_2 D}{Q_2 I_2 C_2 D + 4\lambda_2 EFG}$$

f. Integrating the UICP DLR Models

A major problem in the preceding models for DLRs has been the independent computations of the procurement and repair requirements. As a result, the computed procurement inventory levels for many items would not provide sufficient carcass (NRFI units) to meet the computed repair inventory levels.

To solve this problem, NAVSUP has made some modifications. Under this model , there is only one RISK equiation as shown follows:

$$\text{RISK} = \frac{IC_3D}{IC_3D + \lambda FE}$$

where

$$C_3 = (\frac{G}{D})(C_2) + (1 - \frac{G}{D})C$$

Also, rather than using a procuremant leadtime or a depot level repair turn around time, it uses an average acquisition time as the time horizon for computing the safety level.

The average acquisition time (L_2) is defined:

$$L_2 = (1 - \frac{B}{D})L + (\frac{B}{D})T$$

IV. COMPARISON AMONG THE INVENTORY MODELS AND RECOMMENDATION

A. CHAPTER OVERVIEW

In the previous chapter, several inventory models were reviewed. A mathematical model is a simplified representation of a real world problem, situation, or system. Mathematical models are developed in an effort to determine an optimal solution for the problem it represents. Often real world problems are so complex that even after the simplifying assumptions used in developing the mathematical model, analytic solutions are not possible. In such instances, optimal solutions may only be approximated. In the area of inventory models, most models have been developed based on either a concept of maximizing a business profit where a company such as a department store sells retail goods, or minimizing costs where a company keeps stocks of raw materials on hand to use in a manufacturing process. In either context, the goal is to minimize the costs associated with carrying inventory while ensuring that enough stock is maintained to satisfy demand. In such complex situations, the Requisition Objectives (RO) play a role in limiting maximum stocks. Many businesses target the RO to control their stocks.

In this chapter, the results of a computer program will be provided to compare the inventory models of the Korean Air Force , the Korean Ministry of National Defense (KMND), and UICP. Also, the results of maginal analysis will be provided to check how many items are included within budget limits. The forecasting methods that are used in the Korean Air Force and U.S. military are compared. Repairable item management models will be compared.

Lastly one alternative model for ROKAF will be described.

B. REQUISITIONING OBJECTIVES (RO) COMPUTATION METHOD

1. Assumption

Three basic ingredients form the foundation of this research. The first is formulation of an experimental design. The design should be such that the basic research questions can be answered using relevant models.

The second necessary ingredient is choice of an evaluation tool. The evaluation tool has to be a validated "state of the art" inventory model capable of handling realistic peacetime wartime scenarios in both the stock computation and the aircraft performance evaluation modes. However, this research targets the computation of the RO for

peacetime and consumable items. Theoretical assumptions over models were already provided in chapters II and III. Additionally, although the U.S. Navy uses the max-min inventory system, the results can be compared with those of other models. To compute the safety level of the U.S. Navy's model, normal approximation is applied. In reality, the situations and environments are so different with each other's models. In order to achieve the goal of this research, however, it is assumed that all of the factors used are the same and simplified.

Third, the research questions will be answered by executing the experimental design by each model.

2. Objective and Procurement System

Each model has the same objective which is to minimize system downtime or shorten time weighted requisitions within a total variable cost constraint as discussed in the previous chapter. However, the ROKAF budgeting system for procuring logistic materials does not affect inventory management. The requirement determination formula does not use any budget limit. Currently ROKAF has three sources of supply: the domestic source of supply, foreign commercial source of supply, and the foreign military sales (FMS).

In the case of the Cooperative Logistics Supply Support Arrangement (CLSSA) through the FMS channel, the current RO computation model might be proper to use to determine base supply levels because the ROKAF model was based on the U.S. AFM 67-1 which is the U.S. Air Force base level supply management manual.

Due to the development of domestic industries and change of the FMS policies, the dependability on the FMS has rapidly decreased. ROKAF has required the use of a new inventory model. For the wholesale level initial provisioning process, the U.S. Navy uses COSDIF Range and Depth Computation method and the Variable Threshold model.

3. Operation Level Quantity (OLQ)

The operation level Quantity (OLQ) is the most economical amount of stock needed to perform the day's mission. The OLQ model that ROKAF uses includes two parameters: daily demand rate and unit price. However, the Korean Ministery of National Defense (KMND) states that the time period from receipt of previous reorder quantity to next reorder quantity is 360/n because $n = \sqrt{\frac{DH}{2A}}$ where n is number of orders. KMND recommended the use of the operation level indicated in Table 8 on page 59.

Table 8. OPERATION LEVEL (DAYS) OF KMND

SOS		Class					
FMS	Annual Demand ($)	0-100	100-500	500-1000	1000-5000	5000-10000	Above 10000
	OL	720	180	120	60	45	30
Foreign Commerce	Annual Demand ($)	0-2000	2000-5000	5000-10000	Above 10000	-	-
	OL	720	360	180	60	-	-
Domestic	Annual Demand ($)	0-250	250-500	500-1000	1000-5000	5000-10000	Above 10000
	OL	720	360	180	120	60	30
Others	Annual Demand ($)	0-250	250-500	500-1000	1000-5000	5000-10000	Above 10000
	OL	720	360	180	120	60	30

U.S. Navy is using a stochastic EOQ model as mentioned in the previous chapter. The results of the computer program in Appendix A can compare as shown in Table 9 on page 60.

Table 9. THE RESULTS OF COMPUTER PROGRAM FOR OLQ

ITEM NO.	DEMAND	UNIT PRICE	ROKAF	KMND	U.S. NAVY
CH-001	42.0	52.33	2.0	6.9	42.0
CH-002	12.0	3.52	4.0	23.7	36.0
CH-003	23.0	7.45	3.8	11.3	63.8
CH-004	32.0	15.56	3.1	15.8	52.1
CH-005	10.0	72.80	0.8	3.3	13.6
.	.	.	.	.	.
.	.	.	.	.	.

As shown in Table 9, the U.S. Navy model produces the largest amount of OLQ. The U.S. Navy model includes the shortage cost, frequency of requisition, policy receiver, shelflife, and NSO factors unlike both Korean models. First column identifies each item. Second column shows annual demand of each item. Third column represents the unit price. Fourth column through sixth column shows the results of computer program test for the each model.

To compute the operation level (or EOQ) and total cost, they apply inventory holding costs and ordering costs by the source of supply. Table 10 and Table 11 on page 61 show inventory ordering costs (A) and holding cost rates (H) applied by the ROKAF and U.S. Navy.

Table 10. COMPARISON OF ORDERING COST BETWEEN ROKAF AND U.S. NAVY

ROKAF		U.S. NAVY
SOS	Ordering Cost ($)	
FMS	6.00	A(Q, C(Q), Item Type, Proc Type) = Non-constant
Foreign Commerce	300.00	
Domestic	25.00	
Others	25.00	

Table 11. INVENTORY HOLDING COST RATE (PERCENT)

Cost Rate(%)		ROKAF				U.S.NAVY	
		FMS	Foreign Commerce	Domestic	Other	Consumable	Repairable
Holding Cost Rate(%)		16	26	26	26	23	21
Cost Factors (%)	Investment	10	15	15	15	10	10
	Forecast Error	2	2	2	2	-	-
	Obsolescence	0	5	5	5	10	10
	Warehousing	3	3	3	3	1	1
	Theft Shrinkage	1	1	1	1	2	0

4. Reorder Point Level

The reorder point is the amount of stock necessary to support demand during the replenishment cycle and consists of two elements: the order and shipping time quantity (O&STQ) and the safety level quantity (SLQ).

The O&STQ is the amount of stock necessary to support demand during an average level time. The formula includes the daily demand rate (DDR) and the average order and shipping time factors. The Korean Air Force adopts 90 days for OST directly. Korean MND suggested that OST should be considered by the source of supply. The KMND recommended ROKAF to use the OST as shown in Table 12.

Table 12. APPROVED OST BY KMND

SOS	FMS	Foreign Commerce	Domestic
OST	90	300	0

U.S. military adopts forecasted order and shipping time by the exponential smoothing method for actual data. This forecasting method will be discussed later in this chapter.

The SLQ is an estimate of the standard deviation of demand during the Order and Shipping Time (O&ST). Although ROKAF's model is based on the USAF's model and the basic formula for computing the SLQ is similar, ROKAF's model does not allow for variance of demand and OST.

The U.S. Air Force has adopted the variance of Demand and Order and Shipping Time (VARDO) method which computes the variances based on historical data. Using the VARDO method the new safety level formula is:

$$SLQ = C\sqrt{O\&ST(\text{Variance of Demand}) + (\text{Daily Demand Rate})^2(\text{Variance of OST})}$$

However, this formula is still for base level supply rather than depot level supply.

In the U.S. Navy, also, inventory anaysts consider the variance of demand and OST. Additionally, to find the reorder point, they find the probability of being out of stock at any random point in time (= RISK). According to Mark Code for each item, the U.S. Navy use the normal distribution, Poisson distribution, and binomial distribution to find the reorder point. Korean MND has determined that the demand follows the Poisson process. KMND designed safety levels as shown in Table 13.

Table 13. SAFETY LEVEL TABLE DESIGNED BY THE KOREAN MND

OL D	Under 9	10-18	19-30	31-45	Above 46
30	15	15	15	15	15
45	30	30	30	15	15
60	45	30	30	30	15
90	60	45	45	30	30
120	75	60	45	45	30
180	90	75	60	45	30
360	120	90	75	60	45

To excute the computer program for computing the reorder point (or SLQ and OSTQ), assume that all listed items are FMS materials and OST for the U.S. Navy's

model is 90 days. The results of the computer program are shown in Table 14 on page 63.

Table 14. THE RESULTS OF COMPUTER PROGRAM FOR RP

ITEM NO.	DE-MAND	UNIT PRICE	ROKAF			KMND			U.S. NAVY
			OSTQ	SLQ	RP	OSTQ	SLQ	RP	RP
CH-001	42.0	52.33	10.4	5.6	16.0	3.5	10.4	13.9	16.8
CH-002	12.0	3.52	3.0	3.0	6.0	3.0	3.0	6.0	7.0
CH-003	23.0	7.45	5.7	4.1	9.8	3.8	5.7	9.5	11.2
CH-004	32.0	15.56	7.9	4.9	12.8	3.9	7.9	11.8	14.3
CH-005	10.0	72.80	2.5	2.7	5.2	1.6	2.5	4.1	5.6
.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.

5. Requisition Objectives (RO)

As mentioned in chapter II, RO is the maximum quantity that should be on hand and or on order to sustain current operations. The results of computer program for RO are shown in Table 15.

Table 15. THE RESULTS OF COMPUTER PROGRAM FOR RO

ITEM NO.	DEMAND	UNIT PRICE	ROKAF	KMND	U.S. NAVY
CH-001	42.0	52.33	17.9	20.7	58.8
CH-002	12.0	3.52	10.0	29.6	43.0
CH-003	23.0	7.45	13.6	20.8	75.0
CH-004	32.0	15.56	15.9	27.6	66.4
CH-005	10.0	72.80	6.0	7.4	19.1
.	.	.	.	.	.
.	.	.	.	.	.

These results show that RO depends on political decisions for inventory levels while the U.S. Navy adopts the min-max inventory system (one of the continuous review

models). These results have another meaning the more RO increases, the more sustainability increases. On the other hand, this means a stagnation of cash.

C. REVIEW FOR BUDGET LIMIT BY MARGINAL ANALYSIS

The primary problems of inventory systems with multi-items are how many resources to commit at a given point in time and how should three resources be allocated among the diverse opportunities afforded by the various items to achieve system objectives. ROKAF does not have actual solutions for these problems. For initial provisioning processes and requirements determination within budget limits, they do not have any formula related to these problems. Then, the budgeting list was largely different from actual procurement lists. This situation has caused substantial problems: surplus and stockout.

The marginal analysis theory has been largely limited to economic theory and is rarely if ever applied to actual decision situations because of the inability of a simple static model to describe adequately real decision problems and because of the difficulty of measuring marginal cost and marginal product.

The objective function is to minimize the expected number of shortages for a specific time period subject to total cost is less than the budget limit.

The marginal analysis theory merely states that an efficient mix of productive inputs is that mix for which the ratio of marginal product to marginal cost is the same for each unit. The marginal analysis procedure progressively assigns a unit to the inventory of that item which yields the greatest reduction in expected stockout probability per unit increase in budget usage.

For applying this theory, one assumes that the probability distribution fits the Poisson distribution because the one period's demands for the items to be treated is less than 15. Now, marginal protection and marginal protection per dollar will be calculated by computer. Also, suppose that budget limit per one day is $1500.00

Finally, one can select the kind and number of an item within the budget, which means that the cumulative total costs do not exceed the budget limit. Table 16 on page 65 shows the results of the computer program for finding the priority of an item to be selected on marginal protection per dollar.

Table 16. PRIORITY OF ITEM TO BE SELECTED

PRIORITY	ITEM NO.	UNIT COST	TOTAL COSTS
1	CH-072	0.56	0.56
2	CH-047	3.33	3.89
3	CH-059	3.56	7.45
4	CH-063	4.23	11.68
5	CH-024	4.67	16.35
6	CH-061	0.34	16.69
7	CH-085	0.56	17.25
8	CH-041	4.56	21.81
9	CH-049	2.34	24.15
10	CH-045	0.79	24.94
.	.	.	.
.	.	.	.

The first column shows the ranking of each unit of each item according to the marginal protection per dollar. The second column identifies the item and suggests the units of item. The third column gives the unit cost of the item. The last column gives the cumulative costs which are the amount of cost that have been used up at any given cut-off point. As a result of the computer program , one can purchase within given budget limit.

Table 17 is an answer of this question and summary of the output list.

Table 17. PURCHASED ITEM AND QUANTITY

Purchased Quantity by Item	0	1	2	Above 3	Total
Number of Item	21	60	19	0	100
Total Purchased Quantity	0	60	38	0	98

The number of purchased items within a given budget, $1500, are 79 items and 98 units for those items. Traditionally, if such analysis theory is not adopted like the current Korean Air Force inventory system, they might make an irrational procurement

item list within a given budget limit because they do not have any data about which item is more important.

D. COMPARISON OF REPAIRABLE ITEMS INVENTORY MODELS

Through chapters II and III, ROKAF's inventory model and other inventory models were introduced . Noticing that the annual budget for repairable items takes 70 percent of total annual stock fund budget of the ROKAF, the importance of repairable item management can not be overemphasized. For comparison of repairable items inventory models that were explained in chapters II and III, Table 18 on page 67 provides a subjective summary of the evaluation of the six models explained in this study. The table indicates ratings of good(G), fair(F), or poor(P) for each of the six models rated against sixteen evaluation factors. The ratings which are marked by asterisks correspond to evaluation factors considered to be of greater importance than the others. Evaluation factors marked with one asterisk were subjectively felt to be of significance to this study. Those marked with two asterisks were judged of the greatest significance.

Table 18. MODELS COMPARISON MATRIX

Evaluation Factors	Models					
	KAF	UICP	MET-RIC	MOD MET-RIC	ACM	Dyna MET RIC
Availability Goals **	P	G	G	G	F	G
Constrained Budgets **	P	F	G	G	G	G
Controlled Substitution of Parts **	P	F	F	F	P	G
Operational *	P	P	G	G	G	G
Random Demand, Failures *	P	G	G	G	G	G
Repair Capacity Constraints*	F	P	P	P	P	G
Aircraft Attrition *	P	G	G	G	P	G
Random Repairtimes, OST *	P	G	G	G	G	G
Variable Flying Hour Program *	P	F	G	G	P	G
Link the Repair and Procurement Decision *	P	P	G	G	G	G
Multiservice user	P	F	F	F	P	F
Probabilistic Answers	F	G	G	G	G	G
Multi-Echelon	G	P	G	G	G	F
Multi-Indenture	P	P	P	G	G	G
Be computationally feasible for a System managing thousands of items	G	G	P	P	P	P
Maintenance	P	F	F	F	P	G
Unweighted Rank, G P	2 3	2 2	2 2	3 1	3 3	2 1
Weighted(*&**) Rank, G P	0 9	4 3	8 1	8 1	5 4	10 0

Overall rankings of the six models are shown in the last two columns under the heading "rank" . Each rank contains two numbers divided by a slash. The first number for that model is the total of the G ratings and the second number is the total of the "P" ratings. Based on the criteria shown, the Dyna-METRIC model was a clear winner. (MOD-METRIC looks "good" in unweighted rank.)

E. FORECASTING

The one common element found in any inventory system is some type of forecasting technique for determining future demand. Several factors determine the reliability of a forecasting method. Some of the more important considerations include:

- The time length of the required forecast.
- The level of technical sophistication of the people using the system.
- The cost of forecasting systems depending on computer, manpower, and requirements.
- The currency and accuracy of the available data.
- The importance of the level of accuracy of the forecast.

The Korean Air Force adopts moving average methods to forecast the demand. They do not consider forecasting error. On the other hand, the U.S. military use the exponential smoothing method and it considers the Mean Absolute Deviations (MADs) of random variables. The U.S. Navy uses the "OUT OF FILTER" concept to increase accuracy of forecasts.

F. ALTERNATIVE MODEL FOR THE KOREAN AIR FORCE

1. Probabilistic Models

In chapter III. both deterministic inventory models and probabilistic models were introduced. If demand and lead time are known, uniform, and continuous, they are called deterministic; if they are treated as random variables, they are called probabilistic or stochastic. Traditional inventory models (Economic Order Quantity and Economic Production Quantity) take no account of risk and uncertainty in their formulation under several assumptions.

In real inventory systems, however, the pattern of demand over time will be discrete and irregular. The demand processes of the models introduced in chapter III are all stationary except for Dyna-METRIC. For peace time support, it is probably proper to assume stationary demands since it is likely that changes over time in the demand process occur slowly. An assumption of a dynamic demand process would be reasonable for the case of the deployment of a new system or the phasing out of the old system.

Although we exclude the non-stationary demand process, we still have to deal with the problem of the stochastic process related with the demand pattern since enough is not known about the process which generates demands for items carried by an inventory system to be able to predict with certainty the time pattern of demands. Therefore, the best that can be done is to compute the demand in probabilistic inventory model. When the demand is probabilistic, rather than minimize cost, it is necessary to minimize the expected cost. If the demand distribution is discrete, the expected cost is obtained by summing the different costs for each strategy weighed (multiplied) by their respective

probabilities and then selecting the strategy (demand level) with the lowest expected cost. If the demand distribution is continuous, the minimum expected cost expression is obtained by taking the derivative of expected cost with respect to the variable and then setting it equal to zero. Current inventory models used in the U.S. military are described as the Dyna-METRIC in the U.S. Air Force and the UICP inventory model in U.S. Navy. As shown in chapter III, these models use the normal, Poisson, and negative exponential distributions for requirements computations. The normal distribution has been found to describe many demand functions at the factory level; the Poisson, at the retail level; and the negative exponential, at the wholesale and retail levels.

Although the Korean Air Force inventory system is based on U.S. AFM67-1, it does not consider forecasting errors such as the variance of demand (VOD) and the variance of O&ST (VOO). Of course, the inventory models may be determined according to environment, work station, objectives, manpower, etc. And above distributions should not be automatically applied to any demand situation. Statistical tests should establish the basis for any standard distribution assumption concerning a demand function.

2. Budget Constraint

The objective of a military inventory system is to minimize the cost rather than to maximize the profit. Also, the budget available for investment in spares is either a constraint in all the models or the objective is to achieve the performance at a minimum budget.

As shown in Chapters II and III, the budget constraint is also the major factors to decide the quantity to be purchased for achieving the goal. However, it's actual requirement computation model doesn't have this factor.

In this chapter, a computer program test for marginal analysis over budget limit is one example that might be considered by the Korean Air Force in the future.

3. RO Computation Method

The Requisitioning Objectives level really affects the variation of stocked assets level. Overestimated RO increases total cost to perform the mission while it makes higher the availabilities for the weapon system. On the other hand, underestimated RO might cause a support problem due to the stockout while it can decrease the total cost of performing the mission.

Actually, the Korean Air Force has adjusted the Requisition Objectives levels to retain the stock levels that it needs to achieve objectives.

While the inventory models for weapon system spare parts used to be decided according to top management's policies and a given environment, the current inventory model of Korean Air Force is not enough for depot supply level. The current model may be proper only for CLSSA items of FMS materials.

a. Operational Level Quantity (OLQ)

The OLQ stands for the economic order quantity (EOQ) such as the Wilson EOQ model. As shown the OLQ formula in Chapter II, cost factors such as the ordering cost and holding cost are not described in the formula. The ROKAF need two step computations for OLQ: first, compute the basic EOQ by Wilson EOQ model; second, consider other factors such as top management policies, environment, etc.

b. Safety Level Quantity (SLQ)

As discussed in Chapter III and this chapter, U.S. Air Force SLQ includes the variance of demand and O&ST by items. Risk and uncertainty enter the inventory analysis through many variables, but the most prevalent are variations in demand and lead time. Such variations are absorbed by provision for safety stocks. Safety stocks will be larger for higher stockout costs or service levels, lower holding costs, larger variations in demand, and larger variations in lead time.

c. Ordering and Shipping Time Quantity (O&STQ)

For computing more accurate OSTQ , the application of constant OST has to be avoided. The OST should be adopted item by item.

4. Consideration of Source of Supply (SOS)

ROKAF has relied heavily on the overseas procurement (FMS and Foreign Commercial procurement) for supporting their aircraft weapon systems. Since the end of the 1970's, ROKAF has found many domestic companies from which to purchase equipment and spare parts. This shift to the domestic economy has caused the ROKAF to modify its inventory management system. However, it is still using old models according to U.S. AFM67-1. Accordingly, it has inconsistencies in its inventory management. The ROKAF should consider a new model such as the Dyna-METRIC or UICP models.

5. Repairable Item Inventory Management

The model review and comparison in Chapter III and this chapter gives us guidelines on how the problems can be solved through the mathematical modeling of real world systems. Each of them has a different purpose or specializes in a problem on which the others concentrate less.

The analysis of the models in this chapter enables us to determine which model can best fit into the Korean Air Force inventory system for the management of the repairable items. As a result of the comparisons, METRIC, MOD-METRIC, Dyna-METRIC, and UICP models are suggested for Korean Air Force.

6. Others

Although this study does not in detail discuss forecasting of demand and procurement lead time, these factors are critical for exact requirements determination. The exponential smoothing method for forecasting is recommended; the use of the mean absolute deviations (MADs) and the "out-of-filter" concept may decrease the forecasting error.

V. SUMMARY AND CONCLUSIONS

A description of the current inventory management system of the Korean Air Force was presented in Chapter II. It is evident from this description that the inventory management system is very complex and presents many problems which must be dealt with for any inventory model to be of value to the supply system. Also, a brief overview of the Korean Air Force inventory management system, including the functions and relations of the organizations such as the DSM, DME and DST were described. The source of supply (SOS) was introduced for understanding of this system.

Chapter III provided various theoretical inventory models, assumptions, and the mathematical formulations of the models. Each model has a unique aspect which differentiates it from the others. These theoretical models cover the whole range of inventory from consumable items to repairable items. Also, the U.S. military (U.S. Air Force and U.S. Navy) inventory systems were briefly introduced for future comparison with the Korean Air Force inventory system.

In Chapter IV, the results of comparison of the models discussed in Chapter III was provided. The Korean Air Force inventory system was originally based on the U.S. AFM67-1 which is used for requirements determination at the base supply level. However ROKAF does not consider the variance of demand, and ordering and shipping time. To show and compare how to determine the Requisition Objective (RO) level, a computer program and the results are attached in appendix A. Also, this chapter discussed one example of how to purchase the required items within a given budget through the computer program test of marginal analysis theory. Then, alternative models for the Korean Air Force inventory system was suggested.

Finally, it is emphasized that there are still many shortcomings in the alternative models for the Korean Air Force and additional research must be pursued to eliminate the shortcomings in the alternative models with regard to their applications to the inventory management system of the Korean Air Force.

APPENDIX A. COMPUTER PROGRAM TEST (FORTRAN) FOR COMPUTATION OF RO AND BUDGET CONSTRAINT

```
      PROGRAM CHOI
C***********************************************************************
C    PROGRAM TO COMPARE THE REQUISITIONING OBJECTIVES BY USING WHOLESALE
C    PROVISIONING MODELS OF ROKAF, ROK MND, US NAVY
C        °DESCRIPTIONS FOR SOME VARIABLES
C    D(N); DEMANDS FOR EACH ITEM
C    OLQ(N), MOLQ(N); OPERATION LEVEL QUANTITY
C    OSTQ(N), MOSTQ(N); ORDER AND SHIPPING TIME QUANTITY
C    SLQ(N), MSLQ(N); SAFETY LEVEL QUANTITY
C    CQ(N); CONSTRAINED ECONOMIC ORDER QUANTITY IN THE U.S NAVY
C    CRL(N); CONSTRAINED REORDER POINT IN THE U.S NAVY
C    UP(N); UNIT PRICE
C    RO(N), MRO(N), NRO(N); REQUISITIONING OBJECTIVES
C    BUDGET; BUDGET LIMITATION
C    MP(N,M); MARGINAL PROTECTION
C    MPD(N,M); MARGINAL PROTECTION PER DOLLARS
C    ITEM(N); ITEM NUMBER
C    FPRITY(N*M); FINAL PRIORITY TO BUY
C***********************************************************************
      PARAMETER (N = 101, M =8)
      REAL UP(N), OLQ(N), OSTQ(N), SLQ(N), RO(N), MOLQ(N), MOSTQ(N)
      REAL MRO(N), CQ(N), CRL(N), NRO(N), MP(N,M), MPD(N,M), MSLQ(N)
      REAL BUDGET, MOL(N), MSL(N), DDR, POUT(N), QA(N), QY(N)
      REAL D(N), SHOR(N), F(N), NSO(N), QC(N), MLTD(N), Z(N)
      REAL STD(N), RL(N), PR(N), SEL(N), FCOST(N), FPRTY(N)
      REAL FPRICE(N), G(N), ERR
      INTEGER  NOITEM(N), X, IFACT, IY
      CHARACTER*7 ITEM(N), FITEM(N*M)
C
      DATA BUDGET,ERR/1500.,.0001/
      CALL EXCMS('FILEDEF 01 DISK TDATA DATA A1')
C
C**** INPUT DATA *******************************************************
C
      I = 0
   10 I = I+1
      READ(1,*) ITEM(I),D(I),UP(I),SHOR(I),F(I),PR(I),SEL(I),NSO(I)
      IF(ITEM(I).EQ.'NONE') GOTO 20
      GOTO 10
   20 NUMBER = I-1

      WRITE(3,1020)
      WRITE(3,1060)
      WRITE(3,1030)
      WRITE(3,1060)
      DO 30 I=1,NUMBER
         WRITE(3,1040) ITEM(I),D(I),UP(I),SHOR(I),F(I),PR(I),SEL(I),
     *                 NSO(I)
   30 CONTINUE
```

```
      WRITE(3,1060)
C
C**** COMPUTE RO ROKAF MODEL *******************************************
C
      DO 50 I = 1, NUMBER
           DDR = D(I)/365
           DISC = SQRT(DDR*90*UP(I))
           IF(DDR.EQ.0) THEN
                OLQ(I) = 0
           ELSE
               OLQ(I) = 4.4 * DISC/UP(I)
           ENDIF
           OST=90
           OSTQ(I) = DDR * OST
           SLQ(I) = SQRT(3 * OSTQ(I))
           RO(I) = OLQ(I) + OSTQ(I) + SLQ(I)
   50 CONTINUE
C
C*********** OUTPUT LIST #1 ********************************************
C
      WRITE(3,1200)
      WRITE(3,1240)
      WRITE(3,1210)
      WRITE(3,1240)
      DO 60 I = 1, NUMBER
           WRITE(3,1280) ITEM(I),D(I),UP(I),OLQ(I),OSTQ(I),SLQ(I),RO(I)
   60 CONTINUE
      WRITE(3,1240)
C
C**** COMPUTE RO BY USING THE ROK MND MODEL ****************************
C
      DO 70 I=1, NUMBER
           AV = D(I) * UP(I)
           MOL(I) = 0
           IF(AV.GE.10000) THEN
                    MOL(I) = 30
           ELSE IF(AV.GE.5000) THEN
                    MOL(I) = 45
           ELSE IF(AV.GE.1000) THEN
                    MOL(I) = 60
           ELSE IF(AV.GE.500) THEN
                    MOL(I) = 120
           ELSE IF(AV.GE.100) THEN
                    MOL(I) = 180
           ELSE
                    MOL(I) = 720
           ENDIF
           MOLQ(I) = MOL(I) * DDR
           IF(MOL(I).EQ.30) THEN
                    MSL(I) = 15
           ELSE IF((MOL(I).EQ.45).AND.(D(I).GE.31)) THEN
                    MSL(I) = 15
           ELSE IF((MOL(I).EQ.45).AND.(D(I).GE.0)) THEN
                    MSL(I) = 30
           ELSE IF((MOL(I).EQ.60).AND.(D(I).GE.46)) THEN
                    MSL(I) = 15
```

```
        ELSE IF((MOL(I).EQ.60).AND.(D(I).GE.10)) THEN
                 MSL(I) = 30
        ELSE IF((MOL(I).EQ.60).AND.(D(I).GE.0)) THEN
                 MSL(I) = 45
        ELSE IF((MOL(I).EQ.90).AND.(D(I).GE.31)) THEN
                 MSL(I) = 30
        ELSE IF((MOL(I).EQ.90).AND.(D(I).GE.10)) THEN
                 MSL(I) = 45
        ELSE IF((MOL(I).EQ.90).AND.(D(I).GE.0)) THEN
                 MSL(I) = 60
        ELSE IF((MOL(I).EQ.120).AND.(D(I).GE.46)) THEN
                 MSL(I) = 30
        ELSE IF((MOL(I).EQ.120).AND.(D(I).GE.19)) THEN
                 MSL(I) = 45
        ELSE IF((MOL(I).EQ.120).AND.(D(I).GE.10)) THEN
                 MSL(I) = 60
        ELSE IF((MOL(I).EQ.120).AND.(D(I).GE.0)) THEN
                 MSL(I) = 75
        ELSE IF((MOL(I).EQ.180).AND.(D(I).GE.46)) THEN
                 MSL(I) = 30
        ELSE IF((MOL(I).EQ.180).AND.(D(I).GE.31)) THEN
                 MSL(I) = 45
        ELSE IF((MOL(I).EQ.180).AND.(D(I).GE.19)) THEN
                 MSL(I) = 60
        ELSE IF((MOL(I).EQ.180).AND.(D(I).GE.10)) THEN
                 MSL(I) = 75
        ELSE IF((MOL(I).EQ.180).AND.(D(I).GE.0)) THEN
                 MSL(I) = 90
        ELSE IF((MOL(I).EQ.720).AND.(D(I).GE.46)) THEN
                 MSL(I) = 45
        ELSE IF((MOL(I).EQ.720).AND.(D(I).GE.31)) THEN
                 MSL(I) = 60
        ELSE IF((MOL(I).EQ.720).AND.(D(I).GE.19)) THEN
                 MSL(I) = 75
        ELSE IF((MOL(I).EQ.720).AND.(D(I).GE.10)) THEN
                 MSL(I) = 90
        ELSE IF((MOL(I).EQ.720).AND.(D(I).GE.0)) THEN
                 MSL(I) = 120
        ENDIF
        MSLQ(I) = MSL(I) * DDR
        OST = 90
        MOSTQ(I) = 90 * DDR
        MRO(I) = MOLQ(I) + MSLQ(I) + MOSTQ(I)
   70 CONTINUE
C
C*********** OUTPUT LIST #2 ********************************************
C
      WRITE(3,1260)
      WRITE(3,1240)
      WRITE(3,1270)
      WRITE(3,1240)
      DO 80 I = 1, NUMBER
          WRITE(3,1280) ITEM(I),D(I),UP(I),MOLQ(I),MSLQ(I),MOSTQ(I),
     *                  MRO(I)
   80 CONTINUE
```

```
      WRITE(3,1240)
C
C**** COMPUTE RO BY USING STOCHESTIC (U.S NAVY) MODEL ******************
C
C********** COMPUTE RISK PROBABILITY (POUT) ****************************
C
      DO 100 I = 1, NUMBER
            H = 0.23
            TEMP1 = D(I) * H * UP(I) + SHOR(I) * F(I)
            IF(SHOR(I).EQ.0) THEN
                          POUT(I) = 1
                      ELSE
                          POUT(I) = D(I) * H * UP(I)/TEMP1
            ENDIF
            IF(POUT(I).GT.0.40) THEN
                              POUT(I) = 0.40
            ELSE IF(POUT(I).LT.0.01) THEN
                              POUT(I) = 0.01
                          ELSE
                              POUT(I) = POUT(I)
            ENDIF
  100 CONTINUE
C
C********** COMPUTE BASIC ORDER QUANTITY,QC(I) *************************
C
      DO 110 I = 1, NUMBER
            A = 150
            TEMP2 = 1 - POUT(I)
            IF(POUT(I).EQ.0) THEN
                          QA(I) = SQRT(2 * D(I) * A/H * UP(I))
                      ELSE
                          QA(I) = SQRT(2 * D(I) * A/H * UP(I) * TEMP2)
            ENDIF
            QY(I) = AMAX1(QA(I), 1., D(I))
            QC(I) = AMIN1(QY(I), 12. * D(I))
  110 CONTINUE
C
C********** COMPUTE BASIC REORDER LEVEL ********************************
C

      DO 120 I = 1, NUMBER
            MLTD(I) = OST * DDR
            Z(I) = ANORIN(POUT(I))
            STD(I) = SQRT(D(I))
            RL(I) = MLTD(I) + Z(I) * STD(I)
  120 CONTINUE
C
C********** COMPUTE THE CONSTRAINED REORDER LEVEL, CRL(I), THE CONSTRAINED
C**********       REORDER QUANTITY, CQ(I), AND REQUISITION OBJECTIVES, NRO
C
      DO 130 I = 1, NUMBER
            TEMP3 = AMAX1(RL(I), PR(I))
            TEMP4 = D(I) * SEL(I)
            TEMP5 = AMIN1(TEMP3, TEMP4)
            CRL(I) = AMAX1(0., NSO(I), TEMP5)
            TEMP6 = CRL(I) - DDR * OST
```

```
          TEMP7 = AMAX1(0., TEMP6)
          TEMP8 = D(I) * SEL(I) - TEMP7
          TEMP9 = AMIN1(QC(I), TEMP8)
          CQ(I) = AMAX1(1.,TEMP9)
          NRO(I) = CQ(I) + CRL(I)
  130 CONTINUE
C
C********** OUTPUT LIST #3 *******************************************
C
      WRITE(3,1300)
      WRITE(3,1240)
      WRITE(3,1310)
      WRITE(3,1240)
      DO 140 I = 1, NUMBER
          WRITE(3,1320) ITEM(I), D(I), UP(I), CRL(I), CQ(I), NRO(I)
  140 CONTINUE
      WRITE(3,1240)
C
C**** FINDING THE NUMBER OF EACH ITEMS CAN BE PURCHASED WITH BUDGET LIMI
C
C********* INITIALIZE MP(K,J) AND MPD(J,K) ***************************
C
      DO 160 I = 1, N
          DO 150 J = 1, M
              MP(I,J) = 0.0
              MPD(I,J) = 0.0
  150     CONTINUE
  160 CONTINUE
C
C********* COMPUTE MARGINAL PROTECTION PER DOLLAR, MPD(I,K) ************
C
      DO 180 K = 1, NUMBER
          IY = 0
          J = 0
          CDF = 0.
          G(K) = D(K)/365
          TEMPA = EXP(G(K))
  170     TEMPB = TEMPA * IFACT(IY)
          IF(IY.EQ.0) THEN
                 P = 1./TEMPB
              ELSE
                 P = (G(K) ** IY/TEMPB)
          ENDIF
          IY = IY + 1
          J = J + 1
          CDF = CDF + P
          MP(K,J) = 1. - CDF
          MPD(K,J) = MP(K,J)/UP(K)
          IF(MP(K,J).GE.ERR) GOTO 170
  180 CONTINUE
C
C********* FIND PRORITIES AND TOTAL COSTS ****************************
C
      MAXROW = 0
      MAXCOL = 0
      FCOST(1) = 0.
```

```
      DO 220 I = 1, NUMBER * M
            FPRTY(I) = -99.
            DO 210 K = 1, NUMBER
                  DO 200 J=1, M
                        IF(MPD(K,J).GE.FPRTY(I)) THEN
                               MAXROW = K
                               MAXCOL = J
                               FPRTY(I) = MPD(MAXROW, MAXCOL)
                        ENDIF
  200             CONTINUE
  210       CONTINUE
            FITEM(I) = ITEM(MAXROW)
            FPRICE(I) = UP(MAXROW)
            IF(I.EQ.1) THEN
                    FCOST(I) = FPRICE(I)
                ELSE
                    FCOST(I) = FCOST(I-1) + FPRICE(I)
            ENDIF
            MPD(MAXROW, MAXCOL) = -99.
            IF(FCOST(I).GT.BUDGET) THEN
                        NUMBUD = I - 1
                        GOTO 230
            ENDIF
  220 CONTINUE
C
C*********** OUTPUT LIST #4 ***************************************************
C
  230 WRITE(3,1350)
      WRITE(3,1370)
      WRITE(3,1380)
      WRITE(3,1370)
      DO 240 I = 1, NUMBUD
            WRITE(3,1400) I,FPRTY(I), FITEM(I), FPRICE(I), FCOST(I)
  240 CONTINUE
      WRITE(3,1370)
C
C********* FIND NUMBER OF ITEM PURCHASED *************************************
C

      DO 300 I = 1, NUMBER
            NOITEM(I) = 0
            DO 290 J = 1, NUMBUD
                  IF(FITEM(J).EQ.ITEM(I)) THEN
                                  NOITEM(I) = NOITEM(I) + 1
                  ENDIF
  290       CONTINUE
  300 CONTINUE
C
C*** FORMAT LIST ****************************************************************
C
 1000 FORMAT(I10, F10.1, F10.2, F10.1, 4F5.1)
 1020 FORMAT('1',5(/),10X,'**** INPUT DATA ****',5(/),5X)
 1030 FORMAT(5X,3X,'ITEM NO.',8X,'D',7X,'UP',7X,'SHOR',4X,'F',4X,
     *          'PR',2X,'SEL',3X,'NSO',1X)
 1040 FORMAT(5X,3X,A7,8X,F4.1,3X,F6.2,5X,F6.1,1X,F4.1,3X,F3.1,1X,
     *         F4.1,2X,F3.1)
```

```
1060 FORMAT(5X,65('-'))
1200 FORMAT('1',5(/),10X,'**** OUTPUT LIST #1 ****',5(/))
1210 FORMAT(6X,'NO.',10X,'D',6X,'UP',9X,'OLQ',6X,'OSTQ',7X,'SLQ',
    *       7X,'RO')
1240 FORMAT(5X,65('-'))
1260 FORMAT('1',5(/),10X,'**** OUTPUT LIST #2 ****',5(/))
1270 FORMAT(6X,'NO.',10X,'D',6X,'UP',8X,'MOLQ',6X,'MOSTQ',4X,'MSLQ',
    *       7X,'MRO')
1280 FORMAT(' ',4X,A7,3X,F6.1,3X,F6.2,4(3X,F7.1))
1300 FORMAT('1',5(/),10X,'**** OUTPUT LIST #3 ****',5(/))
1310 FORMAT(10X,'NO.',7X,'D',8X,'UP',8X,'CRP',6X,'CQ',8X,'NRO')
1320 FORMAT(' ',7X,A7,3X,F6.1,3X,F6.2,3X,F7.1,3X,F7.1,3X,F7.1)
1350 FORMAT('1',5(/),10X,'**** OUTPUT LIST #4 ****', 5(/))
1370 FORMAT(' ',60('-'))
1380 FORMAT(2X,'PRIORITY',4X,'MPD', 9X,'ITEM NO.',10X,'UP',7X,
    *        'TOTAL')
1400 FORMAT(2X,I4,4X,E10.3,6X,A7,5X,F8.2,4X,F8.2)
     STOP
     END
     FUNCTION IFACT(IY)
     IFACT = 1
     IF(IY.GT.0) THEN
           DO 10 I = 1, IY
                IFACT = IFACT * I
  10       CONTINUE
     ENDIF
     RETURN
     END
```

THE INPUTS AND OUTPUTS FOR PROGRAM

**** INPUT DATA ****

ITEM NO.	D	UP	SHOR	F	PR	SEL	NSO
CH-001	42.0	52.33	2000.0	10.5	4.0	40.0	2.0
CH-002	12.0	3.52	2000.0	12.0	4.0	40.0	2.0
CH-003	23.0	7.45	1500.0	72.6	2.0	20.0	1.0
CH-004	32.0	15.56	1500.0	6.2	2.0	20.0	1.0
CH-005	10.0	72.80	1500.0	4.3	4.0	20.0	2.0
CH-006	8.0	16.46	2000.0	25.9	4.0	35.0	2.0
CH-007	14.0	6.98	1500.0	9.5	1.0	35.0	2.0
CH-008	9.0	123.65	2500.0	6.0	1.0	40.0	1.0
CH-009	43.0	79.76	2000.0	23.7	2.0	20.0	2.0
CH-010	34.0	23.32	1500.0	12.1	4.0	30.0	4.0
CH-011	45.0	45.65	2000.0	6.4	2.0	20.0	2.0

CH-012	21.0	34.45	2000.0	9.3	2.0	20.0	4.0
CH-013	53.0	59.21	2500.0	13.5	4.0	30.0	4.0
CH-014	8.0	32.80	2000.0	4.5	1.0	40.0	1.0
CH-015	2.0	13.57	1500.0	28.9	4.0	20.0	4.0
CH-016	4.0	42.53	1500.0	8.9	2.0	35.0	2.0
CH-017	17.0	56.43	2000.0	8.5	1.0	35.0	1.0
CH-018	56.0	213.00	2000.0	12.4	2.0	20.0	2.0
CH-019	43.0	23.56	1500.0	6.8	2.0	20.0	2.0
CH-020	60.0	5.90	1500.0	36.4	4.0	15.0	2.0
CH-021	57.0	323.00	2000.0	12.4	2.0	25.0	2.0
CH-022	22.0	23.56	2000.0	22.3	4.0	25.0	4.0
CH-023	13.0	223.22	2500.0	5.2	1.0	40.0	1.0
CH-024	81.0	4.67	1500.0	25.5	4.0	15.0	4.0
CH-025	94.0	13.67	1500.0	45.5	4.0	15.0	4.0
CH-026	29.0	4.56	1500.0	23.4	2.0	20.0	2.0
CH-027	9.0	126.00	2000.0	4.5	3.0	40.0	3.0
CH-028	39.0	54.32	2000.0	7.6	2.0	35.0	2.0
CH-029	24.0	47.98	2000.0	6.4	2.0	30.0	2.0
CH-030	7.0	87.67	2500.0	2.1	2.0	40.0	2.0
CH-031	53.0	11.33	2000.0	23.2	4.0	15.0	4.0
CH-032	43.0	54.65	2000.0	6.3	2.0	30.0	2.0
CH-033	34.0	4.63	2000.0	5.6	2.0	25.0	4.0
CH-034	6.0	43.60	1500.0	2.0	1.0	40.0	1.0
CH-035	87.0	54.60	1500.0	32.4	4.0	20.0	4.0
CH-036	19.0	45.00	2000.0	12.4	2.0	30.0	2.0
CH-037	22.0	12.56	2000.0	8.9	4.0	35.0	4.0
CH-038	32.0	6.42	1500.0	56.7	4.0	15.0	4.0
CH-039	45.0	23.56	2000.0	15.7	2.0	40.0	2.0
CH-040	33.0	34.23	1500.0	11.4	2.0	35.0	2.0
CH-041	67.0	4.56	1500.0	22.4	4.0	30.0	2.0
CH-042	42.0	5.56	2500.0	12.2	4.0	30.0	4.0
CH-043	78.0	23.12	2000.0	13.7	4.0	35.0	4.0
CH-044	5.0	56.56	2500.0	1.2	1.0	40.0	1.0
CH-045	10.0	0.79	1500.0	46.4	4.0	15.0	4.0
CH-046	28.0	3.45	2000.0	14.6	4.0	20.0	4.0
CH-047	78.0	3.33	2000.0	45.5	4.0	25.0	4.0
CH-048	90.0	21.66	2000.0	8.9	2.0	30.0	2.0
CH-049	32.0	2.34	2500.0	6.6	4.0	35.0	4.0
CH-050	5.0	0.45	1500.0	22.2	4.0	35.0	4.0
CH-051	54.0	5.78	1500.0	6.7	2.0	30.0	2.0
CH-052	10.0	5.78	2000.0	2.9	2.0	30.0	2.0
CH-053	74.0	20.98	1500.0	34.4	4.0	15.0	4.0
CH-054	43.0	341.54	2000.0	6.7	1.0	30.0	1.0
CH-055	33.0	22.11	2000.0	4.4	1.0	20.0	1.0
CH-056	37.0	5.69	2500.0	23.4	1.0	30.0	1.0
CH-057	66.0	5.34	2000.0	12.3	4.0	25.0	4.0
CH-058	54.0	5.56	1500.0	34.5	4.0	15.0	2.0
CH-059	76.0	3.56	1500.0	11.4	2.0	20.0	4.0
CH-060	23.0	10.23	1500.0	45.6	2.0	15.0	2.0
CH-061	5.0	0.34	1500.0	12.4	4.0	20.0	2.0
CH-062	87.0	33.54	2000.0	22.4	4.0	30.0	2.0
CH-063	76.0	4.23	2500.0	18.7	2.0	25.0	4.0
CH-064	74.0	13.98	2000.0	6.5	2.0	20.0	2.0
CH-065	56.0	6.79	1500.0	23.3	2.0	40.0	2.0
CH-066	18.0	4.11	2000.0	7.8	1.0	30.0	1.0
CH-067	43.0	23.56	1500.0	9.8	2.0	25.0	1.0

CH-068	12.0	3.56	2000.0	1.3	1.0	20.0	1.0
CH-069	32.0	12.78	2000.0	8.8	2.0	30.0	1.0
CH-070	43.0	4.34	1500.0	43.4	4.0	25.0	2.0
CH-071	15.0	3.50	1500.0	9.9	4.0	20.0	2.0
CH-072	30.0	0.56	2000.0	22.4	4.0	30.0	2.0
CH-073	56.0	67.90	2000.0	7.8	2.0	40.0	1.0
CH-074	66.0	6.78	1500.0	5.6	2.0	25.0	1.0
CH-075	6.0	1.22	1500.0	56.9	4.0	15.0	4.0
CH-076	66.0	10.87	2000.0	33.3	4.0	15.0	2.0
CH-077	59.0	4.56	2000.0	13.3	2.0	40.0	2.0
CH-078	23.0	45.66	2500.0	5.7	1.0	40.0	1.0
CH-079	45.0	3.54	2000.0	12.5	2.0	20.0	2.0
CH-080	34.0	5.21	2500.0	9.0	4.0	20.0	4.0
CH-081	6.0	455.52	2500.0	1.2	1.0	40.0	1.0
CH-082	35.0	8.20	2000.0	11.3	4.0	20.0	1.0
CH-083	4.0	45.45	2000.0	6.6	2.0	35.0	2.0
CH-084	21.0	4.12	1500.0	27.6	4.0	35.0	2.0
CH-085	8.0	0.56	2000.0	34.4	1.0	30.0	1.0
CH-086	22.0	7.88	2000.0	12.4	4.0	25.0	2.0
CH-087	35.0	45.88	1500.0	23.4	4.0	25.0	2.0
CH-088	23.0	3.45	2500.0	5.8	1.0	30.0	1.0
CH-089	78.0	9.45	2000.0	35.6	4.0	35.0	2.0
CH-090	23.0	34.34	2500.0	5.6	2.0	25.0	1.0
CH-091	45.0	9.67	2500.0	45.4	2.0	15.0	1.0
CH-092	12.0	56.56	2000.0	2.2	1.0	40.0	1.0
CH-093	12.0	5.67	1500.0	23.4	4.0	25.0	2.0
CH-094	34.0	6.78	2000.0	22.3	4.0	40.0	1.0
CH-095	9.0	57.78	2500.0	1.1	1.0	40.0	1.0
CH-096	29.0	54.33	2000.0	13.5	4.0	30.0	2.0
CH-097	32.0	4.67	2000.0	6.7	4.0	30.0	4.0
CH-098	20.0	40.00	2000.0	10.0	2.0	20.0	2.0
CH-099	23.0	12.32	1500.0	12.3	1.0	20.0	1.0
CH-100	43.0	43.45	2500.0	5.6	2.0	35.0	2.0

1

**** OUTPUT LIST #1 ****

NO.	D	UP	OLQ	OSTQ	SLQ	RO
CH-001	42.0	52.33	2.0	10.4	5.6	17.9
CH-002	12.0	3.52	4.0	3.0	3.0	10.0
CH-003	23.0	7.45	3.8	5.7	4.1	13.6
CH-004	32.0	15.56	3.1	7.9	4.9	15.9
CH-005	10.0	72.80	0.8	2.5	2.7	6.0
CH-006	8.0	16.46	1.5	2.0	2.4	5.9
CH-007	14.0	6.98	3.1	3.5	3.2	9.8
CH-008	9.0	123.65	0.6	2.2	2.6	5.4

CH-009	43.0	79.76	1.6	10.6	5.6	17.8
CH-010	34.0	23.32	2.6	8.4	5.0	16.0
CH-011	45.0	45.65	2.2	11.1	5.8	19.0
CH-012	21.0	34.45	1.7	5.2	3.9	10.8
CH-013	53.0	59.21	2.1	13.1	6.3	21.4
CH-014	8.0	32.80	1.1	2.0	2.4	5.5
CH-015	2.0	13.57	0.8	0.5	1.2	2.5
CH-016	4.0	42.53	0.7	1.0	1.7	3.4
CH-017	17.0	56.43	1.2	4.2	3.5	8.9
CH-018	56.0	213.00	1.1	13.8	6.4	21.4
CH-019	43.0	23.56	3.0	10.6	5.6	19.2
CH-020	60.0	5.90	7.0	14.8	6.7	28.4
CH-021	57.0	323.00	0.9	14.1	6.5	21.5
CH-022	22.0	23.56	2.1	5.4	4.0	11.6
CH-023	13.0	223.22	0.5	3.2	3.1	6.8
CH-024	81.0	4.67	9.1	20.0	7.7	36.8
CH-025	94.0	13.67	5.7	23.2	8.3	37.2
CH-026	29.0	4.56	5.5	7.2	4.6	17.3
CH-027	9.0	126.00	0.6	2.2	2.6	5.4
CH-028	39.0	54.32	1.9	9.6	5.4	16.8
CH-029	24.0	47.98	1.5	5.9	4.2	11.7
CH-030	7.0	87.67	0.6	1.7	2.3	4.6
CH-031	53.0	11.33	4.7	13.1	6.3	24.1
CH-032	43.0	54.65	1.9	10.6	5.6	18.2
CH-033	34.0	4.63	5.9	8.4	5.0	19.3
CH-034	6.0	43.60	0.8	1.5	2.1	4.4
CH-035	87.0	54.60	2.8	21.5	8.0	32.2
CH-036	19.0	45.00	1.4	4.7	3.7	9.9
CH-037	22.0	12.56	2.9	5.4	4.0	12.4
CH-038	32.0	6.42	4.9	7.9	4.9	17.6
CH-039	45.0	23.56	3.0	11.1	5.8	19.9
CH-040	33.0	34.23	2.1	8.1	4.9	15.2
CH-041	67.0	4.56	8.4	16.5	7.0	31.9
CH-042	42.0	5.56	6.0	10.4	5.6	21.9
CH-043	78.0	23.12	4.0	19.2	7.6	30.8
CH-044	5.0	56.56	0.6	1.2	1.9	3.8
CH-045	10.0	0.79	7.8	2.5	2.7	13.0
CH-046	28.0	3.45	6.2	6.9	4.6	17.7
CH-047	78.0	3.33	10.6	19.2	7.6	37.4
CH-048	90.0	21.66	4.5	22.2	8.2	34.8
CH-049	32.0	2.34	8.1	7.9	4.9	20.8
CH-050	5.0	0.45	7.3	1.2	1.9	10.4
CH-051	54.0	5.78	6.7	13.3	6.3	26.3
CH-052	10.0	5.78	2.9	2.5	2.7	8.1
CH-053	74.0	20.98	4.1	18.2	7.4	29.7
CH-054	43.0	341.54	0.8	10.6	5.6	17.0
CH-055	33.0	22.11	2.7	8.1	4.9	15.7
CH-056	37.0	5.69	5.6	9.1	5.2	19.9
CH-057	66.0	5.34	7.7	16.3	7.0	30.9
CH-058	54.0	5.56	6.8	13.3	6.3	26.4
CH-059	76.0	3.56	10.1	18.7	7.5	36.3
CH-060	23.0	10.23	3.3	5.7	4.1	13.1
CH-061	5.0	0.34	8.4	1.2	1.9	11.5
CH-062	87.0	33.54	3.5	21.5	8.0	33.0
CH-063	76.0	4.23	9.3	18.7	7.5	35.5
CH-064	74.0	13.98	5.0	18.2	7.4	30.7

CH-065	56.0	6.79	6.3	13.8	6.4	26.5
CH-066	18.0	4.11	4.6	4.4	3.6	12.7
CH-067	43.0	23.56	3.0	10.6	5.6	19.2
CH-068	12.0	3.56	4.0	3.0	3.0	9.9
CH-069	32.0	12.78	3.5	7.9	4.9	16.2
CH-070	43.0	4.34	6.9	10.6	5.6	23.1
CH-071	15.0	3.50	4.5	3.7	3.3	11.6
CH-072	30.0	0.56	16.0	7.4	4.7	28.1
CH-073	56.0	67.90	2.0	13.8	6.4	22.2
CH-074	66.0	6.78	6.8	16.3	7.0	30.1
CH-075	6.0	1.22	4.8	1.5	2.1	8.4
CH-076	66.0	10.87	5.4	16.3	7.0	28.6
CH-077	59.0	4.56	7.9	14.5	6.6	29.0
CH-078	23.0	45.66	1.6	5.7	4.1	11.3
CH-079	45.0	3.54	7.8	11.1	5.8	24.7
CH-080	34.0	5.21	5.6	8.4	5.0	19.0
CH-081	6.0	455.52	0.3	1.5	2.1	3.8
CH-082	35.0	8.20	4.5	8.6	5.1	18.2
CH-083	4.0	45.45	0.6	1.0	1.7	3.4
CH-084	21.0	4.12	4.9	5.2	3.9	14.1
CH-085	8.0	0.56	8.3	2.0	2.4	12.7
CH-086	22.0	7.88	3.7	5.4	4.0	13.1
CH-087	35.0	45.88	1.9	8.6	5.1	15.6
CH-088	23.0	3.45	5.6	5.7	4.1	15.4
CH-089	78.0	9.45	6.3	19.2	7.6	33.1
CH-090	23.0	34.34	1.8	5.7	4.1	11.6
CH-091	45.0	9.67	4.7	11.1	5.8	21.6
CH-092	12.0	56.56	1.0	3.0	3.0	6.9
CH-093	12.0	5.67	3.2	3.0	3.0	9.1
CH-094	34.0	6.78	4.9	8.4	5.0	18.3
CH-095	9.0	57.78	0.9	2.2	2.6	5.7
CH-096	29.0	54.33	1.6	7.2	4.6	13.4
CH-097	32.0	4.67	5.7	7.9	4.9	18.5
CH-098	20.0	40.00	1.5	4.9	3.8	10.3
CH-099	23.0	12.32	3.0	5.7	4.1	12.8
CH-100	43.0	43.45	2.2	10.6	5.6	18.4

1

**** OUTPUT LIST #2 ****

NO.	D	UP	MOLQ	MOSTQ	MSLQ	MRO
CH-001	42.0	52.33	6.9	3.5	10.4	20.7
CH-002	12.0	3.52	23.7	3.0	3.0	29.6
CH-003	23.0	7.45	11.3	3.8	5.7	20.8
CH-004	32.0	15.56	15.8	3.9	7.9	27.6
CH-005	10.0	72.80	3.3	1.6	2.5	7.4

CH-006	8.0	16.46	3.9	2.0	2.0	7.9
CH-007	14.0	6.98	27.6	3.5	3.5	34.5
CH-008	9.0	123.65	1.5	1.1	2.2	4.8
CH-009	43.0	79.76	7.1	3.5	10.6	21.2
CH-010	34.0	23.32	11.2	4.2	8.4	23.8
CH-011	45.0	45.65	7.4	3.7	11.1	22.2
CH-012	21.0	34.45	6.9	2.6	5.2	14.7
CH-013	53.0	59.21	8.7	2.2	13.1	24.0
CH-014	8.0	32.80	3.9	2.0	2.0	7.9
CH-015	2.0	13.57	3.9	0.7	0.5	5.1
CH-016	4.0	42.53	2.0	1.0	1.0	3.9
CH-017	17.0	56.43	5.6	2.8	4.2	12.6
CH-018	56.0	213.00	4.6	2.3	13.8	20.7
CH-019	43.0	23.56	7.1	3.5	10.6	21.2
CH-020	60.0	5.90	29.6	4.9	14.8	49.3
CH-021	57.0	323.00	4.7	2.3	14.1	21.1
CH-022	22.0	23.56	7.2	2.7	5.4	15.4
CH-023	13.0	223.22	2.1	1.1	3.2	6.4
CH-024	81.0	4.67	39.9	6.7	20.0	66.6
CH-025	94.0	13.67	15.5	3.9	23.2	42.5
CH-026	29.0	4.56	14.3	4.8	7.2	26.2
CH-027	9.0	126.00	1.5	1.1	2.2	4.8
CH-028	39.0	54.32	6.4	3.2	9.6	19.2
CH-029	24.0	47.98	3.9	2.0	5.9	11.8
CH-030	7.0	87.67	2.3	1.4	1.7	5.5
CH-031	53.0	11.33	17.4	4.4	13.1	34.8
CH-032	43.0	54.65	7.1	3.5	10.6	21.2
CH-033	34.0	4.63	16.8	4.2	8.4	29.3
CH-034	6.0	43.60	3.0	1.5	1.5	5.9
CH-035	87.0	54.60	14.3	3.6	21.5	39.3
CH-036	19.0	45.00	6.2	2.3	4.7	13.3
CH-037	22.0	12.56	10.8	3.6	5.4	19.9
CH-038	32.0	6.42	15.8	3.9	7.9	27.6
CH-039	45.0	23.56	7.4	3.7	11.1	22.2
CH-040	33.0	34.23	5.4	2.7	8.1	16.3
CH-041	67.0	4.56	33.0	5.5	16.5	55.1
CH-042	42.0	5.56	20.7	5.2	10.4	36.2
CH-043	78.0	23.12	12.8	3.2	19.2	35.3
CH-044	5.0	56.56	2.5	1.2	1.2	4.9
CH-045	10.0	0.79	19.7	2.5	2.5	24.7
CH-046	28.0	3.45	55.2	5.8	6.9	67.9
CH-047	78.0	3.33	38.5	6.4	19.2	64.1
CH-048	90.0	21.66	14.8	3.7	22.2	40.7
CH-049	32.0	2.34	63.1	5.3	7.9	76.3
CH-050	5.0	0.45	9.9	1.6	1.2	12.7
CH-051	54.0	5.78	26.6	4.4	13.3	44.4
CH-052	10.0	5.78	19.7	2.5	2.5	24.7
CH-053	74.0	20.98	12.2	3.0	18.2	33.5
CH-054	43.0	341.54	3.5	1.8	10.6	15.9
CH-055	33.0	22.11	10.8	4.1	8.1	23.1
CH-056	37.0	5.69	18.2	4.6	9.1	31.9
CH-057	66.0	5.34	32.5	5.4	16.3	54.2
CH-058	54.0	5.56	26.6	4.4	13.3	44.4
CH-059	76.0	3.56	37.5	6.2	18.7	62.5
CH-060	23.0	10.23	11.3	3.8	5.7	20.8
CH-061	5.0	0.34	9.9	1.6	1.2	12.7

CH-062	87.0	33.54	14.3	3.6	21.5	39.3
CH-063	76.0	4.23	37.5	6.2	18.7	62.5
CH-064	74.0	13.98	12.2	3.0	18.2	33.5
CH-065	56.0	6.79	27.6	4.6	13.8	46.0
CH-066	18.0	4.11	35.5	4.4	4.4	44.4
CH-067	43.0	23.56	7.1	3.5	10.6	21.2
CH-068	12.0	3.56	23.7	3.0	3.0	29.6
CH-069	32.0	12.78	15.8	3.9	7.9	27.6
CH-070	43.0	4.34	21.2	5.3	10.6	37.1
CH-071	15.0	3.50	29.6	3.7	3.7	37.0
CH-072	30.0	0.56	59.2	6.2	7.4	72.7
CH-073	56.0	67.90	9.2	2.3	13.8	25.3
CH-074	66.0	6.78	32.5	5.4	16.3	54.2
CH-075	6.0	1.22	11.8	2.0	1.5	15.3
CH-076	66.0	10.87	21.7	5.4	16.3	43.4
CH-077	59.0	4.56	29.1	4.8	14.5	48.5
CH-078	23.0	45.66	3.8	1.9	5.7	11.3
CH-079	45.0	3.54	22.2	5.5	11.1	38.8
CH-080	34.0	5.21	16.8	4.2	8.4	29.3
CH-081	6.0	455.52	1.0	0.7	1.5	3.2
CH-082	35.0	8.20	17.3	4.3	8.6	30.2
CH-083	4.0	45.45	2.0	1.0	1.0	3.9
CH-084	21.0	4.12	41.4	4.3	5.2	50.9
CH-085	8.0	0.56	15.8	2.6	2.0	20.4
CH-086	22.0	7.88	10.8	3.6	5.4	19.9
CH-087	35.0	45.88	5.8	2.9	8.6	17.3
CH-088	23.0	3.45	45.4	4.7	5.7	55.8
CH-089	78.0	9.45	25.6	6.4	19.2	51.3
CH-090	23.0	34.34	7.6	2.8	5.7	16.1
CH-091	45.0	9.67	22.2	5.5	11.1	38.8
CH-092	12.0	56.56	3.9	2.0	3.0	8.9
CH-093	12.0	5.67	23.7	3.0	3.0	29.6
CH-094	34.0	6.78	16.8	4.2	8.4	29.3
CH-095	9.0	57.78	3.0	1.8	2.2	7.0
CH-096	29.0	54.33	4.8	2.4	7.2	14.3
CH-097	32.0	4.67	15.8	3.9	7.9	27.6
CH-098	20.0	40.00	6.6	2.5	4.9	14.0
CH-099	23.0	12.32	11.3	3.8	5.7	20.8
CH-100	43.0	43.45	7.1	3.5	10.6	21.2

1

**** OUTPUT LIST #3 ****

NO.	D	UP	CRP	CQ	NRO
CH-001	42.0	52.33	16.8	42.0	58.8
CH-002	12.0	3.52	7.0	36.0	43.0

CH-003	23.0	7.45	11.2	63.8	75.0
CH-004	32.0	15.56	14.3	52.1	66.4
CH-005	10.0	72.80	5.6	13.6	19.1
CH-006	8.0	16.46	5.3	24.0	29.3
CH-007	14.0	6.98	7.8	42.0	49.8
CH-008	9.0	123.65	5.4	9.8	15.2
CH-009	43.0	79.76	17.6	43.0	60.6
CH-010	34.0	23.32	15.2	43.8	59.0
CH-011	45.0	45.65	17.1	45.0	62.1
CH-012	21.0	34.45	10.5	28.3	38.8
CH-013	53.0	59.21	20.5	53.0	73.5
CH-014	8.0	32.80	5.3	17.9	23.2
CH-015	2.0	13.57	4.0	6.0	10.0
CH-016	4.0	42.53	3.3	11.1	14.4
CH-017	17.0	56.43	8.8	20.0	28.7
CH-018	56.0	213.00	18.6	56.0	74.6
CH-019	43.0	23.56	17.2	49.3	66.5
CH-020	60.0	5.90	23.8	115.8	139.6
CH-021	57.0	323.00	18.0	57.0	75.0
CH-022	22.0	23.56	10.9	35.1	46.0
CH-023	13.0	223.22	6.2	13.0	19.2
CH-024	81.0	4.67	30.4	151.2	181.6
CH-025	94.0	13.67	34.5	95.2	129.6
CH-026	29.0	4.56	13.4	87.0	100.4
CH-027	9.0	126.00	5.1	9.8	14.9
CH-028	39.0	54.32	15.4	39.0	54.4
CH-029	24.0	47.98	10.9	25.8	36.7
CH-030	7.0	87.67	4.3	10.3	14.6
CH-031	53.0	11.33	21.5	78.5	100.0
CH-032	43.0	54.65	16.3	43.0	59.3
CH-033	34.0	4.63	15.2	98.4	113.5
CH-034	6.0	43.60	4.0	13.5	17.5
CH-035	87.0	54.60	30.8	87.0	117.8
CH-036	19.0	45.00	9.8	23.6	33.3
CH-037	22.0	12.56	10.9	48.0	58.9
CH-038	32.0	6.42	14.5	81.0	95.5
CH-039	45.0	23.56	18.9	50.2	69.1
CH-040	33.0	34.23	14.4	35.7	50.1
CH-041	67.0	4.56	26.0	139.1	165.2
CH-042	42.0	5.56	17.9	99.8	117.7
CH-043	78.0	23.12	28.8	78.0	106.8
CH-044	5.0	56.56	3.5	10.9	14.4
CH-045	10.0	0.79	6.1	30.0	36.1
CH-046	28.0	3.45	13.1	84.0	97.1
CH-047	78.0	3.33	29.5	175.7	205.2
CH-048	90.0	21.66	31.5	90.0	121.5
CH-049	32.0	2.34	14.5	96.0	110.5
CH-050	5.0	0.45	4.0	15.0	19.0
CH-051	54.0	5.78	21.9	110.9	132.8
CH-052	10.0	5.78	6.1	30.0	36.1
CH-053	74.0	20.98	28.3	74.0	102.3
CH-054	43.0	341.54	13.3	43.0	56.3
CH-055	33.0	22.11	14.1	44.5	58.7
CH-056	37.0	5.69	16.2	92.6	108.8
CH-057	66.0	5.34	25.7	127.6	153.3
CH-058	54.0	5.56	21.9	113.1	135.0

CH-059	76.0	3.56	28.9	167.7	196.6
CH-060	23.0	10.23	11.2	54.4	65.7
CH-061	5.0	0.34	4.0	15.0	19.0
CH-062	87.0	33.54	31.6	87.0	118.6
CH-063	76.0	4.23	28.9	153.9	182.7
CH-064	74.0	13.98	27.3	83.8	111.1
CH-065	56.0	6.79	22.5	104.2	126.8
CH-066	18.0	4.11	9.4	54.0	63.4
CH-067	43.0	23.56	17.7	49.2	66.8
CH-068	12.0	3.56	7.0	36.0	43.0
CH-069	32.0	12.78	14.5	57.4	71.9
CH-070	43.0	4.34	18.2	114.3	132.5
CH-071	15.0	3.50	8.2	45.0	53.2
CH-072	30.0	0.56	13.8	90.0	103.8
CH-073	56.0	67.90	19.9	56.0	75.9
CH-074	66.0	6.78	25.4	113.4	138.8
CH-075	6.0	1.22	4.3	18.0	22.3
CH-076	66.0	10.87	25.7	89.4	115.2
CH-077	59.0	4.56	23.5	130.6	154.0
CH-078	23.0	45.66	10.8	25.8	36.6
CH-079	45.0	3.54	18.9	129.4	148.3
CH-080	34.0	5.21	15.2	92.7	107.9
CH-081	6.0	455.52	2.6	6.0	8.6
CH-082	35.0	8.20	15.5	75.0	90.5
CH-083	4.0	45.45	3.3	10.8	14.1
CH-084	21.0	4.12	10.5	63.0	73.5
CH-085	8.0	0.56	5.3	24.0	29.3
CH-086	22.0	7.88	10.9	60.6	71.5
CH-087	35.0	45.88	15.5	35.0	50.5
CH-088	23.0	3.45	11.2	69.0	80.2
CH-089	78.0	9.45	29.5	104.3	133.8
CH-090	23.0	34.34	11.0	29.7	40.8
CH-091	45.0	9.67	18.9	78.3	97.2
CH-092	12.0	56.56	6.1	16.9	23.0
CH-093	12.0	5.67	7.0	36.0	43.0
CH-094	34.0	6.78	15.2	81.3	96.4
CH-095	9.0	57.78	4.8	14.6	19.4
CH-096	29.0	54.33	13.1	29.0	42.1
CH-097	32.0	4.67	14.5	95.0	109.5
CH-098	20.0	40.00	10.1	25.7	35.8
CH-099	23.0	12.32	11.2	49.6	60.8
CH-100	43.0	43.45	16.8	43.0	59.8

1

**** OUTPUT LIST #4 ****

PRIORITY	MPD	ITEM NO.	UP	TOTAL

1	0.141E+00	CH-072	0.56	0.56
2	0.578E-01	CH-047	3.33	3.89
3	0.528E-01	CH-059	3.56	7.45
4	0.444E-01	CH-063	4.23	11.68
5	0.426E-01	CH-024	4.67	16.35
6	0.400E-01	CH-061	0.34	16.69
7	0.387E-01	CH-085	0.56	17.25
8	0.368E-01	CH-041	4.56	21.81
9	0.359E-01	CH-049	2.34	24.15
10	0.342E-01	CH-045	0.79	24.94
11	0.328E-01	CH-079	3.54	28.48
12	0.327E-01	CH-077	4.56	33.04
13	0.310E-01	CH-057	5.34	38.38
14	0.302E-01	CH-050	0.45	38.83
15	0.257E-01	CH-020	5.90	44.73
16	0.256E-01	CH-070	4.34	49.07
17	0.247E-01	CH-058	5.56	54.63
18	0.244E-01	CH-074	6.78	61.41
19	0.238E-01	CH-051	5.78	67.19
20	0.214E-01	CH-046	3.45	70.64
21	0.209E-01	CH-065	6.79	77.43
22	0.204E-01	CH-089	9.45	86.88
23	0.195E-01	CH-042	5.56	92.44
24	0.192E-01	CH-033	4.63	97.07
25	0.180E-01	CH-097	4.67	101.74
26	0.177E-01	CH-088	3.45	105.19
27	0.171E-01	CH-080	5.21	110.40
28	0.169E-01	CH-056	5.69	116.09
29	0.167E-01	CH-026	4.56	120.65
30	0.166E-01	CH-025	13.67	134.32
31	0.152E-01	CH-076	10.87	145.19
32	0.136E-01	CH-084	4.12	149.31
33	0.134E-01	CH-075	1.22	150.53
34	0.131E-01	CH-064	13.98	164.51
35	0.131E-01	CH-094	6.78	171.29
36	0.131E-01	CH-038	6.42	177.71
37	0.120E-01	CH-091	9.67	187.38
38	0.119E-01	CH-031	11.33	198.71
39	0.117E-01	CH-066	4.11	202.82
40	0.115E-01	CH-071	3.50	206.32
41	0.112E-01	CH-082	8.20	214.52
42	0.101E-01	CH-048	21.66	236.18
43	0.919E-02	CH-002	3.52	239.70
44	0.908E-02	CH-068	3.56	243.26
45	0.875E-02	CH-053	20.98	264.24
46	0.832E-02	CH-043	23.12	287.36
47	0.820E-02	CH-003	7.45	294.81
48	0.742E-02	CH-086	7.88	302.69
49	0.657E-02	CH-069	12.78	315.47
50	0.632E-02	CH-062	33.54	349.01
51	0.597E-02	CH-060	10.23	359.24
52	0.595E-02	CH-047	3.33	362.57
53	0.571E-02	CH-072	0.56	363.13
54	0.570E-02	CH-093	5.67	368.80
55	0.539E-02	CH-004	15.56	384.36

56	0.539E-02	CH-007	6.98	391.34
57	0.531E-02	CH-059	3.56	394.90
58	0.496E-02	CH-099	12.32	407.22
59	0.492E-02	CH-039	23.56	430.78
60	0.472E-02	CH-067	23.56	454.34
61	0.472E-02	CH-019	23.56	477.90
62	0.468E-02	CH-052	5.78	483.68
63	0.466E-02	CH-037	12.56	496.24
64	0.455E-02	CH-024	4.67	500.91
65	0.447E-02	CH-063	4.23	505.14
66	0.391E-02	CH-055	22.11	527.25
67	0.388E-02	CH-035	54.60	581.85
68	0.381E-02	CH-010	23.32	605.17
69	0.327E-02	CH-041	4.56	609.73
70	0.272E-02	CH-057	5.34	615.07
71	0.257E-02	CH-077	4.56	619.63
72	0.256E-02	CH-100	43.45	663.08
73	0.254E-02	CH-011	45.65	708.73
74	0.253E-02	CH-040	34.23	742.96
75	0.248E-02	CH-022	23.56	766.52
76	0.228E-02	CH-013	59.21	825.73
77	0.214E-02	CH-074	6.78	832.51
78	0.210E-02	CH-089	9.45	841.96
79	0.209E-02	CH-073	67.90	909.86
80	0.208E-02	CH-001	52.33	962.19
81	0.205E-02	CH-020	5.90	968.08
82	0.205E-02	CH-025	13.67	981.75
83	0.203E-02	CH-032	54.65	1036.40
84	0.199E-02	CH-087	45.88	1082.28
85	0.198E-02	CH-079	3.54	1085.82
86	0.187E-02	CH-028	54.32	1140.14
87	0.178E-02	CH-058	5.56	1145.70
88	0.178E-02	CH-090	34.34	1180.04
89	0.172E-02	CH-051	5.78	1185.82
90	0.162E-02	CH-012	34.45	1220.27
91	0.157E-02	CH-065	6.79	1227.06
92	0.155E-02	CH-049	2.34	1229.40
93	0.148E-02	CH-070	4.34	1233.74
94	0.141E-02	CH-096	54.33	1288.07
95	0.139E-02	CH-009	79.76	1367.83
96	0.134E-02	CH-078	45.66	1413.49
97	0.133E-02	CH-076	10.87	1424.36
98	0.133E-02	CH-098	40.00	1464.36

LIST OF REFERENCES

1. Korean Air Force Manual 67-1, *Supply Support* , Korean Air Force Publication Center, 1979.

2. Department of Defense, DSAMM DOD 5105.38M.

3. Richard J. Tersine, *Principles of Inventory and Materials Management* , Elsevier Science Publishing Co., Inc., New York, 1988.

4. Hood, Major William C., *A Handbook of Supply Inventory Models* , MS Thesis, AFIT GLM LSMA/87S-35. Air Force Institute of Technology (AU), Wright-Patterson AFB, OH, SEP. 1987.

5. Crawford, G. B., *Palm's Theorem for Nonstationary Processes* , Report R-2750-RC, Santa Monica, CA., The RAND Corporation, October 1981 (ADA117089).

6. Craig C. Sherbrook, *A Multi Echelon Technique for Recoverable Item Control* , Report RM-5078-PR, Santa Monica, CA., The RAND Corporation, November 1966 (AD645684).

7. Muckstadt, J. A., *A Model for a Multi Item, Multi Echelon, Multi Indenture Inventory System* , Management Science V.20, No.4 PP472-481, 1973.

8. Department of Defense, *Measures of Military Essentiality* , Contract No. SD-271, Logistics Management Institute, Washington DC. August 1972.

9. Raymond Pyles, *The Dyna-METRIC Readiness Assessment Model* , Report R-2886-AF, Santa Monica, CA., The RAND Corporation, July 1984.

10. R. J. Hiiestad, *Dynamic Multi-Echelon Technique for Recovable Item Control* , Report R-2785-AF, Santa Monica, CA., The RAND Corporation, July 1982.

11. Department of Air Force, *Standard Base Supply System* , AFM67-1, Volume II, Part two, Washington: HQ' USAF, January 1987.

12. Air Force Logistics Command. *Requirements Procedures for Economic Order Quantity (EOQ) Items* , AFLCR 57-6, Wright-Patterson AFB, OH: HQ' AFLC. August 1984.

13. Navy Supply Systems Command, *Inventory Management* , NAVSUP Publication 553, 1984.

14. F. Russell Richards and Alan W. McMasters, *Wholesale Provisioning Models: Model Development* , Final Report for period Janualy 1982- June 1983, Naval Postgraduate School, Monterey, CA.. September 1983.

15. Alan W. McMasters, *Wholesale Provisioning Models: Model Evaluation* , Naval Postgraduate School, Monterey, CA., May 1986.

16. Hadley, G. and Whitin, T. M., *Analysis of Inventory Systems* , Prentice Hall, Inc., 1963.

INITIAL DISTRIBUTION LIST

		No. Copies
1.	Defense Technical Information Center Cameron Station Alexandria, VA 22304-6145	2
2.	Library, Code 0142 Naval Postgraduate School Monterey, CA 93943-5002	2
3.	Defense Logistics Studies Information Exchange US Army Logistics Management College Fort Lee, VA 23801-6043	1
4.	Professor Dan Trietsch, Code 54Tr Department of Administrative Sciences Naval Postgraduate School Monterey, CA 93943-5000	1
5.	Professor Gail Fann, Code 54Fa Department of Administrative Sciences Naval Postgraduate School Monterey, CA 93943-5000	1
6.	Capt. Choi, Sung-Kyu 20 Tong 2 Ban 101 Byun-Ji Bongchun 5 Dong, Kwanak-Ku, Seoul, 151, Korea	4
7.	Library of Air Force Academy Chongwon-Kun, Chung Buk 370-72, Korea	3
8.	Keebom Kang, Code 55Ka Department of Operation Research Naval Postgraduate School Monterey, CA 93943-5000	1
9.	Park, Rae-Youn SMC#2329 Naval Postgraduate School Monterey, CA 93943-5000	1
10.	Son, Hyung-Chan SMC#1666 Naval Postgraduate School Monterey, CA 93943-5000	1

11. Kim, Chang-Ho 1
SMC#1671 Naval Postgraduate School
Monterey, CA 93943-5000

12. Ko, Man-Young, LT/Col. 1
HQ AFLC / MI-KS
WP AFB, OH 45433

13. Lee, Kang-Yeun 1
SMC#2186 Naval Postgraduate School
Monterey, CA 93943-5000

Thesis
C44886014 Choi
c.1 Computing Requisitioning Objectives for the Korean Air Force inventory management system.